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NOTES *and* SALES LETTERS

COMPLIMENTS OF

WESTON ELECTRICAL INSTRUMENT CO.

NEWARK, NEW JERSEY

U. S. A.

A SELECTED
COMPILATION OF
NOTES AND SALES LETTERS

PERTAINING TO

WESTON
ELECTRICAL MEASURING INSTRUMENTS

Edition of Nineteen Twenty-four

WESTON ELECTRICAL INSTRUMENT CO.
NEWARK, NEW JERSEY
U. S. A.

WESTON
ELECTRICAL INSTRUMENT CORP.
SUCCESSORS

SX

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Foreword

Early in 1921 this Company conceived the idea of providing its representatives with systematic and pertinent information that would enable them to better understand the product they were selling and the conditions surrounding their conception and manufacture.

We have received so many requests for copies of some of these letters from Electrical Engineers and Technical Educators that we have been prompted to select a few of them and issue this pamphlet to those of our customers who might express an interest for more information than a catalog would give concerning certain electrical measuring instruments.

If the idea meets with any marked approval we shall be encouraged to expand this work, but we wish it to be understood that this compilation is not presumed to be a technical treatise and that the subject matter is presented in commercial form rather than as a literary effort.

SALES DEPARTMENT
WESTON ELECTRICAL INSTRUMENT CO.
Newark, N. J.

Preliminary—Historical—Imitation

Weston Instruments were first manufactured commercially in 1888. Prior to that time it was impossible to obtain accurate or dependable commercial measuring instruments. Such commercial instruments as were obtainable were nothing more than extremely crude and unreliable indicators utterly unsuited for use in the realm of precise measurement.

Indeed, measurements required with any degree of accuracy had to be made of necessity in laboratories equipped with very expensive, cumbersome yet delicate and specially constructed devices, such as the tangent galvanometer. The use of such devices involved much computation and repetition of observations resulting in loss of time. They were also seriously affected by external influences such as the earth's field.

Dr. Weston, the present president of the Weston Electrical Instrument Company, while actively engaged in research and development work in various phases of the electrical industries, realized how tremendously he was handicapped by not having a suitable means for quickly and accurately making electrical measurements. Consequently, he abandoned practically all other work and started out to accomplish that which other leading scientists of that day had failed to do, namely, to produce a type of direct-current instrument which would be direct reading, accurate, generally serviceable and durable, and of reasonable cost.

This was a tremendous task, but how well it was performed is testified to by the quick discarding of all previously known types of instruments and the enormous demand that arose for the new Weston type.

Dr. Weston became so intensely interested in this branch of the electrical industry that it has constituted his dominating activity. His pioneer and epoch-making work was characterized by designing and producing various types of direct-current instruments for portable, switchboard and laboratory use.

But even so his labors had only commenced. They soon embraced research work with negligible temperature co-efficient resistance alloys, standard cells, etc. In fact, he undertook an extensive variety of investigations, all contributing to the development and perfection of the direct-current and subsequently the alternating-current instruments so well known to-day throughout the civilized world. He was also the inventor of the direct reading type of electrodynamometer alternating and direct-current indicating instrument which form of instrument is the universally recognized standard for precise alternating current measurements.

During the thirty-three years of the Company's existence Dr. Weston has continued actively engaged at his task. He has been

the main directive influence of the most highly developed electrical instrument manufacturing concern in the world and he together with a large staff of specially trained engineers have indefatigably labored to better the art of electrical measurements.

The introduction of the Weston pivoted movable coil permanent magnet direct-current instrument revolutionized the art of electrical measurement. As a result other instrument manufacturers were either forced to copy the Weston instrument or discontinue their business. Not only was this true of the early permanent magnet direct-current instruments but it has also been true of practically all subsequent types or forms of Weston Instruments.

The early Weston Instruments were very completely protected by basic and detail patents. At first, ways and means were sought and efforts were made for circumventing the Weston patents. Then the bolder competitors put aside all scruples and endeavored to imitate.

The attempted imitations were poor in quality and performance, so for a time the Weston Company did not pay much attention to them but continued to develop its own field of endeavor. The policy of ignoring the competitor emboldened others to enter the field and imitate. Some of these failed to make a product that would sell and others dragged out a hand-to-mouth existence; while others through means of specious claims or advertisements had careers of somewhat greater length. This condition prevailed for years. Many so-called competitors came into being and went out of existence.

Finally, shortly before the original basic patents expired, the Weston Company brought between fifty and sixty simultaneous injunction suits against competitors. Our claims were upheld by the courts in every case but one, which was a minor case of relatively little importance. This litigation involved a tremendous waste of time to fight piracy. It not only cost large sums of money but also took effort from more useful kinds of work. The worst predicament arose when it became evident that all but two of the infringers were practically without financial means. The courts had authorized the Weston Company to recoup for damages but when they attempted to do so the infringers could not pay these damages or would not protect those who had purchased their instruments. Then practically all of these imitators abandoned the field. Only the two largest companies continued and they manufactured under license from the Weston Company. However, imitation did not cease. New companies sprang into existence and worked out similar precarious careers long after the Weston basic patents had expired. This condition still prevails and probably always will prevail.

The question is, why did none of these companies make a real success of their efforts. The answer is plain. None of them

were actuated by the same high ideals of service. None of them would devote the earnest, hard work to development. Apparently, none had the ability to devise methods for manufacturing the intricate parts essential to perfect their products. None of them were capable of performing the Weston character of workmanship without which accuracy, serviceability and durability cannot be assured. Consequently none of them even to-day ranks in quality of product with Weston.

Although Weston Instruments have been widely imitated and Weston ideas freely appropriated, no one manufacturer has succeeded in producing their equal. The position held by the Weston Company is to-day as strong as, if not stronger than, at any time during its career; and its reputation for producing the highest grade instruments is international.

Design

An electrical measuring instrument is strictly speaking an electromechanical device. That is to say it must possess clearly defined electrical characteristics and also perform certain mechanical functions. Being an electromechanical device it follows quite obviously, that satisfactory design necessitates experimental work in the realms of physics and chemistry.

In reality every Weston Instrument is, so to speak, a harmony of electrical, mechanical, physical and chemical properties.

When we speak of design, we include the principle of operation, the selection of materials, the proportioning of parts and even the development of tools in order that the composite result—the instrument—shall be the best adapted to all requirements met with in ordinary practical use.

It will thus be understood that a high grade instrument is not the simple device that it seems to be. On the contrary it is an intricate electromechanical contrivance that has been developed after exhaustive and painstaking research and it ranks very high in the field of scientific achievement.

It is sometimes very amusing to hear a competitor argue that his instrument has one characteristic that exceeds the excellence of the Weston Instrument. In remote cases these claims may be true; but—and this is the point to bear in mind—if such specific betterment has been obtained it is more than offset by loss of satisfaction in all other respects and on the whole the competitive instrument is vastly inferior to the Weston and hence sold under specious claims. In other words the true gauge of the grade or value of an instrument is the serviceability and accuracy under the conditions of use for which it is intended and any other gauge of its value will prove grossly misleading.

With this understanding in mind we shall proceed to indicate a few of the problems that arise in designing instruments, but it must be appreciated that the subject can only be treated very superficially in the limited space available. In the following paragraphs are mentioned a few of the most interesting examples of problems that are involved in "Design."

Practically all Weston Instruments employ springs for the purpose of opposing the forces acting to deflect the movable system. These springs must always function as a mechanical device but in certain types of instruments the spring must also perform the additional service of conducting current into and away from the movable coil and thus function as an electromechanical device. The qualities essential to a spring performing a mechanical service are—strength and elasticity—and when we superimpose suitable electrical qualities such as proper conductivity, low temperature co-efficient and negligible thermo-electromotive force to other conductors used in instrument

construction, it will be appreciated that the problem is of exceptional difficulty.

Dr. Weston and his associates have compounded, analyzed and experimented upon thousands of different alloys in order to solve these and similar problems.

An ammeter spring must be of low resistance or high conductivity material because of the low resistance of the ammeter. The best metallic conductors such as copper, aluminum and silver while possessing proper characteristics of conductivity are soft and ductile and entirely unsuited for making good springs. Springs made from these materials would be permanently distorted through being put under tension, causing a set or fatigue to occur which would prevent the movable system from returning to its original zero position, thus destroying the accuracy of the instrument. Also the change in resistance of these metals is relatively large with changes in temperature. Consequently it became necessary to use some form of alloy in order to get a proper spring material.

It can readily be seen that ordinary alloys which would have proper electrical characteristics would fail to respond to the hardening treatment necessary to give the spring its proper elasticity. It was only after the most exhaustive experimental and research work extending over a period of many years, that entirely satisfactory spring alloys were obtained. From these, Weston springs have been produced.

Simultaneously with the investigations on spring alloys, a great many other alloys were investigated for manifold uses such as shunt strip material, resistance wire for use in adjusting voltmeters and wattmeters, material for pointers, damper vanes, field supports, etc.

In certain types of instruments such as the electrodynamometer wattmeters it is very essential that the phase angle of the instrument be made as small as possible. To do this requires a very careful design of the disposition and character of the metallic parts adjacent to the movable system so that they offer the greatest obtainable resistance to the generation of foucault or eddy currents. In Weston Instruments of this type careful consideration was given to this problem with the result that by properly selecting the alloy material comprising the coil supports and disposing of this material in the most efficacious manner, the phase angle of the instruments was reduced to a minimum.

In the early years of electrical instrument construction the idea that a magnet could be made permanent was derided and scoffed at. Dr. Weston has demonstrated that it is possible to do so, provided a steel having proper characteristics is given the correct heat treatment in hardening and then used to form a part of a properly designed magnetic circuit of very small air-gap or reluctance. The fact of obtaining a reliably permanent magnet

was revolutionary but without this achievement the direct-current instruments of to-day would be radically inferior. This Company has been using permanent magnets for well over thirty years and magnets installed in the first instruments it made (which are occasionally received by us for repair), show no appreciable change in strength.

Pointers used in Weston Instruments also present a very nice problem. These pointers are composed of aluminum alloy tubing. Because various sizes of instruments require various sizes of pointer the tubing dimensions vary and means must be provided for making them. Often this tubing is of such exquisite design that the shell or wall is ¾ of a thousandth of an inch thick. Each pointer is balanced, and for the precision instruments a great refinement in balancing is required. This is accomplished by means of balancing nuts of different weights which are adjusted to the proper position on a screw thread of exceedingly fine pitch that is cut on the balance cross of the pointers. Then too, instruments used on alternating currents must have trussed pointers to prevent their vibration at critical frequencies. This trussing must be so placed as to bring the critical vibration frequency outside of the limits of frequency on which the instrument is to be used. Weston Alternating-Current Instruments were the first that could be used within the guaranteed limits on any commercial frequency.

The movable coils used in the various instruments differ according to the characteristics required for the instruments. It is always necessary to correctly design the coils with due regard to the current to be used by the instrument; the allowable temperature error; in the case of alternating-current instruments the allowable frequency error due to self-inductance; the damping qualifications; the weight of the coil as compared to the actuating forces; the stiffness or strength of the coil, etc.

Pivots must be of suitable size to accommodate different sizes of coils. Their points must be ground to the proper angle and with the proper roundness at the extreme tip so that crushing will not occur and friction will be eliminated. Nothing is left to chance in this work as each pivot is individually ground, tested and inspected.

Jewels must be in proportion with pivot size and shaped so as to eliminate friction and yet properly support the movable coil in any position.

In the design of cases for strength and shielding, the material used and its disposition must be carefully studied so that the operating characteristics of the finished instrument shall be entirely satisfactory.

These are only a few of the problems to be solved when designing an instrument. Each other part entering into the com-

pleted instrument presents other problems all of which must be individually considered.

Finally, tools for the commercial production of the instruments must be made and each tool involved requires a similar study as do the instrument parts, both as to material used and general construction.

The value of any instrument depends entirely upon the manner in which each factor, electrical or mechanical, has been brought into permanent relation with the numerous other factors in order to secure the best possible combination or whole. Therefore, when investigating an instrument which may initially conform to certain superficial tests with reasonable accuracy, it is advisable to ascertain whether it is so designed and constructed that it will meet the demands of ordinary practice as accurately under continued service as at the time of purchase.

Quality

The quality of Weston products is conceded by practically every one, yet it is not unusual to hear a prospective customer say, "A Weston Instrument is too good for my purpose; I do not want to pay for unnecessary refinement."

A consideration of the facts of the case at once proves the absurdity of such a statement. The business of the Weston Company was founded with quality as a fundamental characteristic; it has grown and prospered through a strict adherence to that characteristic. If the Company was to deviate from this policy it would retrogress in direct ratio to the extent of deviation. The careers of competitive manufacturers prove this; so does the testimony of at least nine out of ten users of instruments.

To the man who has only a superficial knowledge of electrical measuring instruments it may seem that the heavier and stronger parts used by competitive manufacturers may result in an instrument of greater durability which will be better adapted for certain classes of work. Nothing could be further from the truth. Let us see why this is so.

It is evident that the only moving parts of an indicating electrical measuring instrument are those which compose the movable system, including the springs. The movable system moves as a unit. It has only one function which is to tend to rotate under the electrical influence brought to bear upon it. When rotating it causes the pointer attached to it to move across a calibrated scale. Consider how different this is from the functions demanded of moving parts in ordinary machinery where stresses and strains of a severe nature are imposed on the various parts. In the functioning of the movable coil there are no loads imposed as in the case of the electric motor—no blows to be struck as with a riveter or hammer. It is quite clear that we have a special and peculiar electro-mechanical problem to consider.

It would seem to follow then that if the members of the movable system are constructed to give an adequate strength with a large factor of safety to the movable system as a whole, that it is relatively immaterial whether the parts are heavy or light. Such a conclusion is grossly misleading. Assuming that a movable system is properly designed to perform its mechanical functions, it is of the utmost importance that the weight be reduced to the lowest possible value without reducing the factor of safety. Let us briefly consider the effect of movable system weight reduction on the perfection of a measuring instrument.

The movable system is usually supported by hardened steel pivots bearing in jewels; the less weight these pivots and jewels have to support the greater will be their life. If two movable systems are supported on pivots having approximately the same

shape and area of contact with the jewels, and one of these systems weighs twice as much as the other, the lighter system will have a potential life of approximately four times the life of the heavier system.

An indicating instrument is depended upon to denote the instantaneous values of the forces acting within the circuit. In many instances these are rapidly fluctuating values. The lighter the mass of the movable system and the more nearly to the center of rotation the mass is placed, the more quickly will the movable system follow the circuit fluctuations. Also with proper damping facilities the oscillatory motion of the movable system is effectively eliminated. It is appropriate to call attention to the damping characteristic of standard Weston movable coil systems. These are designed to overswing the top mark by a scale division when suddenly caused to deflect from zero to top mark, falling back to the actual top mark value. This assures the user that the instrument is without friction. If the pointer was to reach its true position quickly and without overswing there would be a lurking suspicion in the user's mind that the motion had been suddenly arrested by some foreign cause. This condition is sometimes met with in competitors' instruments. It is more frequently the case that the instrument damping is such that the pointer continues to oscillate over a considerable range of scale for a more or less extended period of time before finally coming to rest. It can readily be appreciated that such a condition is exceedingly unsatisfactory because it results in loss of time in taking readings and on fluctuating circuits prevents accurate readings being obtained.

Nevertheless, instruments possessing the foregoing characteristics are offered to the public as being capable of rendering service equivalent to that rendered by Weston Instruments; but from what has been said it should be evident that service depends upon quality.

Having a movable system of light weight, the forces required to produce a deflection can be held to a minimum. This of course means that the electrical energy required to produce the mechanical force will also be a minimum which in turn results in an economical and accurate condition of operation.

In recapitulation, the light weight movable system assures an instrument of indefinitely long life if not abused, of freedom from pivot friction, of serviceability under all operating conditions and of economy in operation and accuracy in indication.

Quality in the design of the movable system has been specifically referred to because it serves as a typical example of the effect of scientific design on the functioning of an electrical measuring instrument. Similarly, practically every part entering into the construction of an instrument might be cited to show the advantages of quality design. Thus it might be shown why it is

essential to employ in practically every instance pointers of tubular construction made from special alloys; why special springs adapted to serve the dual purpose of electrical conductors and mechanical control producers are used; why balance crosses have specially fine threads, why balance nuts, lock washers, etc., are as small as consistently can be used. Less refinement and heavier and coarser parts are employed by some of our competitors, but they result in vastly inferior instruments.

Weston Instruments are quality built instruments but in no case is the quality feature carried to such extremes than an unnecessary degree of perfection is reached or that the instrument fails to show an advantageous betterment in its operating characteristics.

No instrument is so expensive as the one which is inaccurate and unserviceable and of short life.

From what has been briefly said it should be apparent that no purchaser of a Weston Instrument is buying unnecessary refinement. On the contrary, it should now be understood that such purchasers are buying conscientiously developed instruments in the construction of which neither labor, time, nor expense has been stinted, and in which every effort has been devoted to producing a truly serviceable product.

Durability and Permanence

Durability is defined as THE POWER OF LONG RESISTANCE TO CHANGE. Permanence is defined as THE QUALITY OF CONTINUING IN THE SAME STATE OR OF CONTINUING WITHOUT ANY CHANGE THAT DESTROYS THE ESSENTIAL NATURE. From these definitions it is apparent that the terms Durability and Permanence have practically the same meaning yet there is a slight and important difference, for in the term Durability there is involved a question of more or less definite time, while in the term Permanence infinite time is assumed. The importance of these characteristics in measuring instruments is readily appreciated if it is remembered that instruments to be of any value must retain their accuracy of indication over extended periods of time.

What elements of instrument design and construction affect these characteristics? It has been stated previously that movable coils are made as light as consistently possible to possess adequate strength, so that pivot and jewel wear due to coil rotation may be reduced to a minimum. (Hence Permanence or Durability can only be assumed if deterioration through friction is eliminated to the highest possible degree.)

Again using the movable coil as an example; the position of the turns on the coil with respect to the air-gap, that is, their distance from the center of rotation, is one of the factors determining the operating current of the instrument. If these change their position, the current value will also change, with a resulting inaccuracy in the instrument indication. Therefore the coil windings must be constructed so as to prevent warping and giving way of the material binding the turns together. To accomplish this necessitates the use of a suitable varnish having a proper binding power and the ability to retain that power as time elapses. After innumerable careful experiments a suitable varnish has been obtained, but it is necessary to be certain that the varnish as it is made from time to time is exactly the same in quality as the standard that has been established.

Another interesting study is the spring. The spring is subjected to mechanical stresses as the instrument deflects, which tend to distort it and give it a temporary or permanent set. This must not be permitted because it is required that the pointer of the instrument should return to its zero position with accuracy after the current has ceased to flow through the instrument. To obtain a spring which will not show distortion after use, it must be made from an alloy of correct composition for conductivity which after being given the dimensions of the completed spring receives the proper aging or treatment to give it the needed elasticity. To procure proper alloys and determine efficient treating methods was

an arduous task. As the imposing and removing of stresses in the spring is repeated many thousand times during the life of an ordinary instrument, the spring material must not show fatigue and disintegration with time. The most careful supervision of spring manufacture is therefore essential.

Resistance wires used in instruments as well as shunt strips are alloys which must possess the essential characteristics of relatively high specific resistance and very low or negigible resistance temperature co-efficient. Alloys often possess the peculiar property of disintegrating with time. To assure permanence to an instrument it is therefore essential that resistance alloy be free from this disintegration phenomenon. It was necessary to experiment with and compound more than one thousand alloys to secure a suitable limited selection for use in Weston Instruments. These statements apply with equal force to the alloys used in shunts because the material is subjected to sudden and large changes in temperature as current flows or ceases to flow through the shunt. All Weston alloys are made in our own plant under expert supervision.

A very important factor affecting permanence is the retaining of the magnet strength. Permanent magnets are only obtained by employing a suitable steel, hardened under the most favorable conditions, coupled with a proper design of the magnetic circuit. To obtain the right steel is no easy task. When it is remembered that the quality of the steel and its hardening temperature are intimately related, the enormity of the problem will be appreciated. This problem resolves itself into that of reproduction of magnets in large quantities all having the same characteristics and this can only be accomplished by means of expert supervision of the testing of the steel and of the hardening and aging treatments.

Not only must instrument parts have proper characteristics to insure permanence, but these parts must be mechanically retained in their essential positions in such a way that change is impossible. To accomplish this specially fine pitch screw threads are used throughout (on one group of pointers the number of threads to the inch are the finest that have ever been produced commercially on stock of the size employed) ; specially designed lock washers are used wherever necessary; certain of the most delicate parts are riveted together; parts subject to bending must be strengthened; parts carrying loads must be sufficiently liberal in proportion to prevent flow of the metal of which they are composed as well as crushing and other defects.

From these few examples it is evident that to secure Durability and Permanence, the design must possess certain necessary properties which properties must be constantly verified through test and inspection; processes of manufacture must be rigidly adhered to and diligently checked up.

Such is the procedure followed in the Weston Plant. Each step comes under the supervision of a trained expert operating in his own special field. Thus are Durability and Permanence assured in Weston Instruments as is attested to by the world-wide reputation deservedly enjoyed by this Company.

Damping

Purpose

The purpose of damping as applied to deflecting electrical measuring instruments may be said to be threefold, namely: (1) to bring the movable element quickly to rest, so that no time need be lost in the taking of readings; (2) to permit the movable element to respond to and follow changes in the quantity being measured, without effect from the natural period of oscillation of the instrument; (3) to impart to the movable element a time constant of retardation which will adapt the instrument to some particular case of measurement. The first two purposes are fulfilled in the standard Weston Instruments and the third purpose in a number of special instruments which have been made by the Weston Company.

Theoretically perfect damping is obtained when the movable element is brought to rest without overswing, in the shortest possible time. This condition is not usually fulfilled in practice, because of the possibility of the existence of slight friction in the instrument. The movable element is permitted to overswing a slight amount after which it is brought to rest. Damping of this character assures the user of the instrument of the absence of friction, causing him to have implicit confidence in the indications.

Damping Methods

Damping may be accomplished in the following ways: (1) String Damping, (2) Friction Disc Damping, (3) Oil Damping, (4) Air Damping, (5) Magnetic Damping, (6) Generator Action of a Movable Coil.

In the following text each form of damping will be referred to in the order mentioned. All of these forms of damping are not at present in practical use; they are considered because they represent important steps in the advancement of the art of damping.

String Damping

Probably the earliest attempt to damp the motion of the movable element of an indicating electrical instrument by mechanical means, was that which employed a tightly stretched string bearing on the pointer. The normal position of the string was a small distance above the pointer, so that the movable element would swing freely in response to any circuit changes. When a reading was to be taken the motion of the movable element was stopped by depressing a button which caused the string to bear on the pointer. It is obvious that the operation of this damper was very unsatisfactory. When the string pressure was removed the movable element became subject to oscillation due to changes in the circuit conditions and unless the damper was very skillfully

manipulated when the button was depressed the pointer would be firmly held and prevented from following the circuit fluctuations.

This form of damping was never used in Weston Instruments.

Friction Disc Damping

Just prior to the year 1890, Dr. Edward Weston placed on the market, a portable form of electrodynamometer instrument which was provided with a friction disc damper. The scheme is illustrated in Figure 1.

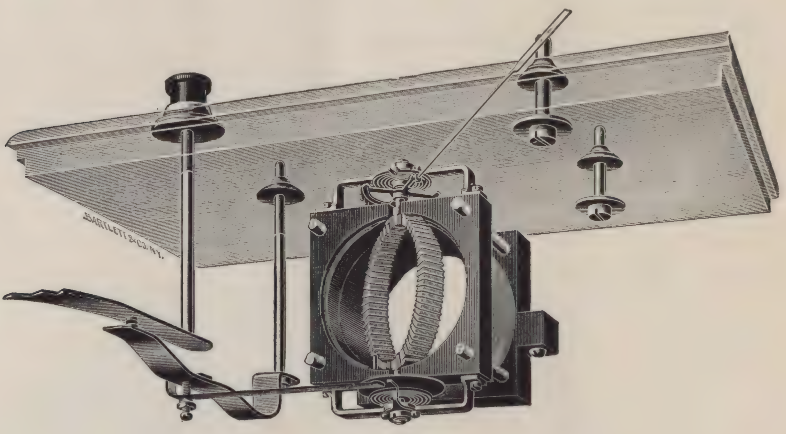


Figure 1

A metal disc was mounted on the movable coil staff just above the lower spring as shown in the illustration. The disc rotated with the movable coil. An arm, controlled from the outside of the instrument, could be brought to bear on the surface of the disc by depressing a button. The design of the arm mechanism was such that the pressure of the arm on the disc was under the control of the operator, who with a little skill could obtain fairly good damping.

This method, as well as the string method previously mentioned, produced damping only when a reading was to be taken. In between readings the movable element would oscillate freely if the circuit characteristics were at all of a varying nature.

Oil Damping

In 1896, Dr. Weston invented a horizontal edgewise form of switchboard instrument in which the field and movable coils were immersed in oil. As the movable coil would tend to move in the oil, the motion would be retarded by the viscosity of the oil. By reason of this the coil motion was very effectually damped.

This form of damping however, possesses certain objectionable features such as leakage of the oil and the necessity of remov-

ing the oil during transportation of the instrument. Also, there is no practical way of applying oil damping to instruments having the movable coil axis in a horizontal plane.

For some years this form of damping was used in a number of standard instruments in the Weston Laboratory, but it was discontinued when the improved form of air damper was available.

Air Damping

Not being satisfied with existent forms of mechanical damping, Dr. Weston gave his attention to the design of an air damper, which was the forerunner of the standard form of damper for use on instruments of the electrodynamometer and electromagnetic types.

The air damper depends for its action upon the compression of air on the advancing side of a movable vane and the rarefaction of air on the receding side. This action is scarcely perceptible in open air or even in a closed chamber, unless the resistance to the leakage of air from one side of the vane to the other is made comparatively great.

The damping force of an air damper can be increased in three general ways: (1) by increasing the area of the vanes, (2) by increasing the speed at which the vanes travel, (3) by increasing the resistance to leakage of air around the vanes.

The first two methods are simple and easy to apply and are therefore in common use by instrument makers. These methods are, however, fundamentally defective, since every increase in

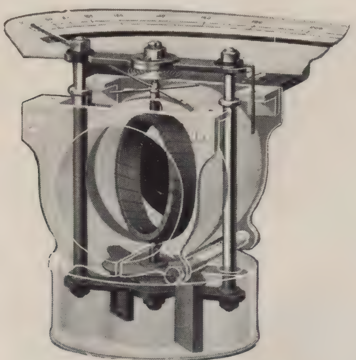


Figure 2

damping force is accompanied by an increase in weight and moment of inertia of the movable element.

The third method presents many practical difficulties, but it is the only correct method to use, as the damping force can be increased very much without change in weight or moment of inertia of the movable element. This method can be used with success only by the most skillful design accompanied by accurate workmanship.

Figure 2 illustrates an early form of Weston air damper applied to an electrodynamometer instrument as successor to the Friction Disc Damper. Although this early form of air damper was generally satisfactory in its operation, it presented many opportunities for mechanical improvement. A long and exhaustive study of the problem resulted in the production of the air damper illustrated in Figure 3.

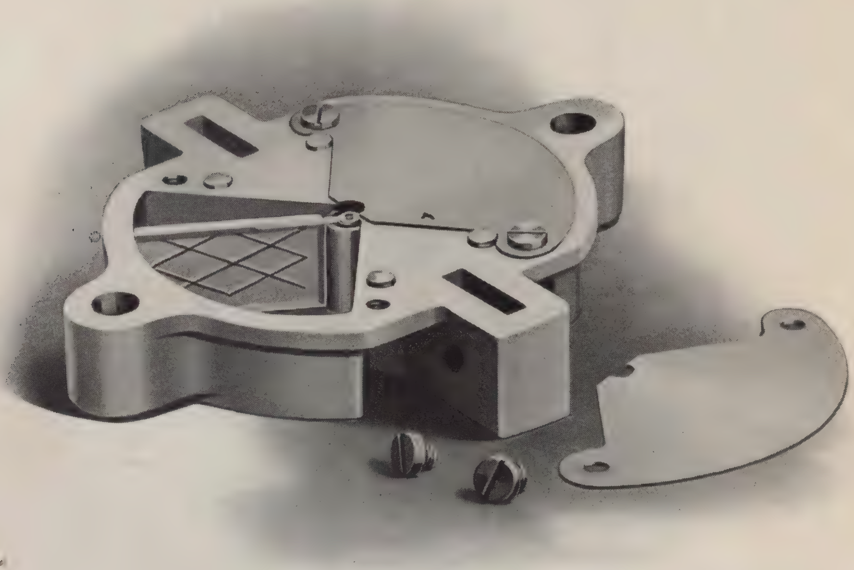


Figure 3

This form is now used on all Weston electrodynamometer instruments as well as on other instruments requiring a double vane air damper.

The essential parts of this damper are the damper box and the vanes. The damper box is a one piece casting having recessed

chambers in which the vanes move. In Figure 3 a vane is shown in position in the chamber.

Each chamber is closed by means of a cover plate as shown at the rear of the illustration. The construction of the damper box is such that the chambers are practically entirely closed, there being only a small opening near the inner edge of the vane to permit fastening the vane to the movement staff.

The vanes consist of thin sheets of light weight alloy, stiffened by ribs stamped into them and by the bending of the edges to conform to the surfaces of the damping chambers. The vanes are fastened to a cross-bar which is attached to the pointer staff.

A movement of the vanes is accompanied by compression of the air on the advancing sides of the vanes and by a rarefaction of the air on the receding sides. The compressed air leaks through the clearance space into the rarefied part of the chamber. The quality of damping depends on the degree of air leakage. The leakage is controlled by properly proportioning the clearance space and the width of the turned over edges of the vanes.

The design has been worked out so well in the Weston air damper that the motion of the movable element is perfectly controlled producing ideal practical damping with a slight overswing of the pointer.

Figure 4 shows the application of the air damper to the

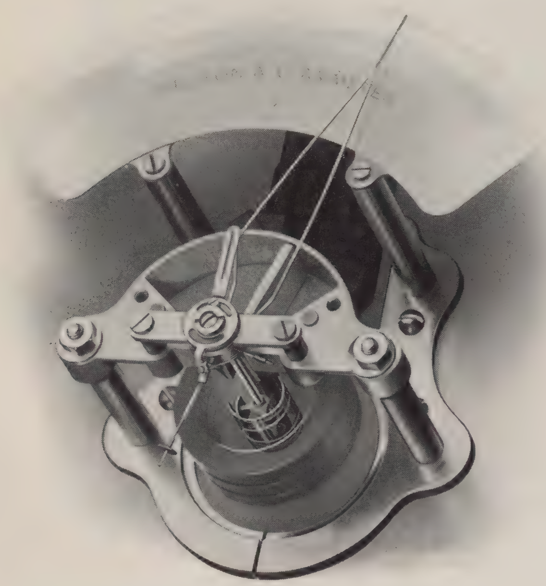


Figure 4

Weston electromagnetic or movable-iron type of instruments. The air chamber cover is removed showing the vane in position. It is only necessary to use one vane, which is placed near the upper end of the movable coil staff.

Magnetic Damping

The common form of damping for permanent magnet instruments is the magnetic damping which is produced by the generation of eddy currents in a metallic frame upon which the coil is wound.

The eddy currents are generated in the frame as it moves in the permanent magnet field. A torque is produced by the reaction of this current on the magnetic field, which acts to oppose the motion of the movable coil. The strength of the damping force depends on the resistance of the metallic frame, its speed of rotation and the strength of the permanent magnet field in which the frame moves. It is obvious that the resistance of the frame is the easiest to control, and it is by changing the frame resistance that the quality of damping is varied in practice.

The frame resistance depends on the proper selection of the material of which it is composed and the thickness of the frame. Change in damping is usually accomplished by changing the frame thickness.

Magnetic damping is also applied to electrodynamometer and electromagnetic types of instruments by some manufacturers. They employ an aluminum disc attached to the movable element staff, the disc being caused to move between the poles of small permanent magnets. This usually results in a very great increase in weight and moment of inertia of the movable element.

Generator Action of a Movable Coil

When a permanent magnet instrument is connected to an external circuit for use, the movable coil winding becomes a part of a closed circuit. As the coil moves in the permanent magnet field a current is generated in the movable coil by its rotation through the magnetic field. The reaction of this current on the magnetic field produces a torque which opposes the motion of the coil just as the metallic frame does in the magnetic form of damping.

The damping force depends upon the strength of the permanent magnet field, the number of turns on the coil, the rate at which the turns move in the field, and the resistance of the circuit.

This action is present in all permanent magnet instruments, but if the circuit resistance is very high it will not have any appreciable effect on the damping. In such cases the movable coil is provided with a metallic frame and magnetic damping is employed.

Under certain conditions it is required that an instrument should have a high sensitivity and low resistance. A very weak

spring must be used to get the sensitivity and with the low resistance the generator damping effect becomes preponderant. In this case the metallic frame would be omitted.

At times it is found that an instrument without a metallic frame is under-damped because of insufficient generator action; if a metallic frame is used the instrument becomes over-damped because of the too great effect of the combined magnetic damping and generator action. In such a case the metallic frame is omitted and the movable coil shunted until proper damping is obtained. This procedure very slightly reduces the sensitivity of the instrument which is usually unimportant.

Another method for increasing damping by generator action is to place one or more short circuited turns on the movable coil, the number of turns being determined by the conditions under which the instrument must operate.

It is general practice to use a metallic frame and magnetic damping whenever possible. An instrument which must be without a metallic frame will be given the correct damping quality by the proficient designer through the use of one of the schemes mentioned, in conjunction with the proper proportioning of the several factors affecting damping, consideration being given to their effect on the electrical characteristics of the instrument.

Damping by generator action is most commonly manifested in galvanometers, pyrometer millivoltmeters and millivoltmeters used across low resistances such as shunts.

This is not an exhaustive treatment of the subject of damping, but merely alludes to means employed and results achieved and is intended to direct attention to this very important and essential characteristic of electrical measuring instruments.

Alloys Used in Weston Instruments

It is questionable whether the average instrument user has any real idea of the important part played by negligible temperature co-efficient resistance alloys in the perfection of electrical measuring instruments. However that may be, the fact remains that unless the present well-known alloys of this character were available, we should still be woefully lacking in the means of making quick and accurate electrical determinations.

The history of the development of suitable alloys of high specific resistance with negligible temperature co-efficient and negligible thermoelectric effect properties is exceptionally interesting. Dr. Weston was the discoverer of the prototype of all well-known alloys of this character used to-day.

Dr. Weston originally became interested in his alloy investigations in the early 80's. His incentive to explore the subject arose from the fact that he experienced considerable trouble in connection with field rheostats for the dynamos he was then engaged in building. These rheostats contained as resistance elements spiral springs of an alloy called "German Silver," which, although then the best resistance alloy available, nevertheless proved very troublesome because of actual variation in its resistance properties with passage of current and consequent variations in temperature. He was also continually hampered in many other direction such as, for example, in bridge work because bridge coils were then invariably wound with German Silver wire which had varying resistance when in actual use or in different atmospheric temperatures. Indeed, the arms of most bridges varied from each other.

This was largely due to the fact that there was no actual standard composition of German Silver and hence the term was more or less generic. Even the best German Silver then made was unsuitable because it required the use of correcting factors and because extraordinary precautions were necessary when using it in precise work.

It will, therefore, be understood why a man whose life work has been crowded with earnest and conscientious endeavors to advance the arts with which he has been associated would rebel against the annoyances and inconveniences arising from the use of unsatisfactory resistance alloys and why it was that Edward Weston decided that the subject was of such great importance as to warrant his concentration upon it.

Dr. Weston spent about four years in all at this task and it was during that time he also became interested in the broader subject of precise commercial electrical measurements, so that in a sense both problems were interwoven.

From what has been said, it is evident that German Silver in the forms then available was wholly unsatisfactory and further experiments with other proportions and forms of German Silver

alloy resulted in finally dismissing that alloy from consideration.

It was well understood, of course, that any of the known element metals were wholly unsatisfactory because all of them have a very definite increase of electrical resistance with increase of temperature and many of them cannot be satisfactorily worked mechanically even were they satisfactory in other respects. Hence, this new research work was conducted with an exceedingly large number of alloys composed of varying proportions of all metals which seemed to offer any encouraging prospects. This was a prodigious task because several thousand alloys were planned for and actually prepared. From these, test pieces were worked up and then each piece was subjected to very thorough and exhaustive tests. Months elapsed before it became evident that the greatest hope of success lay with alloys of nickel-copper or nickel-copper-manganese composition.

The indefatigable nature of Dr. Weston's work is unbelievable and of intense interest because it was only after establishing certain laws based upon innumerable tests that steady progress was accomplished. In course of time an alloy was found with half the temperature co-efficient of German Silver. Then followed others with still lower temperature co-efficients; but of these, many had to be discarded because of their undesirable mechanical properties when being worked into sheets or wires.

The first alloy that was believed to be worthy of commercializing was Constantan, which is known also under various trade names as Ideal, Ia Ia, etc. This was a nickel-copper alloy with a very small temperature co-efficient, but a comparatively large thermoelectromotive force to copper. Its discovery was a splendid achievement and marked a great stride forward in the industry. Almost any other man would have considered his task completed, but Dr. Weston knew that Constantan failed to possess all the desirable properties he sought, so that he carried on his work without interruption and finally produced the alloy "Manganin," which upset all theories relative to resistance alloys and which may be said to be the prototype of all resistance alloys now in use for electrical measurement and standardization purposes and for an infinite variety of other work.

When it is said that Manganin upset all theories regarding metals or alloys, it is meant that up to 1884 it was substantiated as a physical law that the electrical resistance of all metals increased as the temperature increased. Manganin (the nickel-copper-manganese alloy) in the proportions in which it was finally made DID NOT behave in this manner. In fact, it was found that it had practically zero change in resistance with change in temperature and that under certain conditions would ACTUALLY DECREASE in resistance with increase in temperature. Furthermore, it had a high specific resistance and an extremely small thermoelectromotive force to copper.

Having realized his object, Dr. Weston suspended alloy work and, unfortunately, for about two years became forced to protect some of his interests of an entirely different nature. This unanticipated digression was unfortunate because through oversight he had neglected to patent Manganin in Germany, and what might have been expected actually took place — namely, the Germans appropriated the results of his work insofar as Germany might be concerned. Indeed, they claimed the discovery to be of German origin and commenced to manufacture Manganin and sell it into this country while Dr. Weston was otherwise engrossed.

But a little later, in 1886, when Dr. Weston had applied for the earliest patents and was perfecting his first direct-current permanent magnet movable coil instruments, he needed Manganin, and then followed another exceptionally interesting chapter in his alloy work. In time the fraudulent nature of the claims made by the Germans was completely discredited and credit given where it actually belonged.

The principal use for alloys in the manufacture of electrical measuring instruments and their accessories is for the purpose of procuring a satisfactory form of resistance.

Alloys used for this purpose are usually in the form of wires and sheets. The wire form is commonly wound on spools or in coils and placed within the instrument. The sheet form is practically limited to use as a part of shunts, which may or may not be placed within the instrument, depending on the shunt size and other considerations.

An electrical measuring instrument, in order to indicate correctly, must remain constant over a very extensive range of change in temperature. It must also be free from electrical influences caused in its several parts by differences in the temperature of those parts.

This requires that resistances shall remain of constant value regardless of temperature and that local thermal currents shall not be set up by different kinds of resistance materials being brought into contact with one another.

These facts were well understood by Dr. Weston and every effort was made to embody them in the first Weston Instruments. However, at that time an alloy known as 18 per cent German Silver was practically the only one available for resistance work, and this alloy would change to a very large extent with moderate changes in temperature. Likewise it had a high thermoelectromotive force with respect to copper so that when used in shunts it would cause local currents in the instrument unless the entire shunt was at the same temperature.

Since this alloy would increase in resistance with an increase in temperature, the instrument would not correctly indicate unless at the temperature at which it had been standardized. To correct for this error was a laborious and unsatisfactory task.

As stated, Dr. Weston discovered Manganin in 1884, but it was not commercially employed until some years later. It was first made on a commercial basis in Germany and there employed in the construction of standard instruments.

There being no source of supply in America, The Weston Company imported it in the form of sheets for use in its high-grade shunts. Constantan was used when a wire form of resistance was needed.

Up to 1908 no American source of supply of Manganin had been developed. Finding it inconvenient to continue its importation and desiring to employ it in its wire form as well as in its sheet form, The Weston Company installed a complete metallurgical department where Manganin was compounded, rolled into sheets, drawn into wire and completely made ready for use in instrument construction. With the completion of this department Manganin superseded all other alloys for resistance purposes.

In addition to its zero temperature co-efficient and very small thermoelectromotive force, it has a relatively high specific resistivity so that a high value of resistance is obtainable with the use of a comparatively small quantity of the material. When artificially aged at the proper temperature its structure becomes permanent and it therefore retains its resistivity without change.

Dr. Weston's discovery of Manganin was one of the greatest factors leading to the remarkable advancement which has been made in the art of electrical measurement.

In constructing movable coils for use in electrodynamometer instruments it is desirable to obtain a very light weight coil having as low a resistance as possible. This is practically obtained in Weston Instruments by using an alloy of aluminum, which is exceedingly light in weight and possesses a low specific resistance.

Another special aluminum alloy is used for the tubular pointers of Weston Instruments, and for the coil staffs and air damper vanes in the electromagnetic and electrodynamometer instruments. This alloy must be capable of resisting large bending and twisting forces without becoming permanently affected.

The supports holding the field coils in the electrodynamometer instruments are manufactured from an alloy of very high specific resistance. They are cut out so as to present a long path of high resistance to such eddy currents as may be generated in them as they come under the effect of the current in the field coils. The eddy currents must be kept negligibly small or they will have an appreciable effect on the instrument indication.

From the foregoing it is evident that no alloy can be used in a Weston Instrument unless it possesses the proper characteristics which help to make the finished instrument best for general service. Only after much experimenting and research on the part of Dr. Weston and his associate engineers has it been possible to gather together those alloys which completely fill these requirements.

Weston Electrodynamometer Wattmeters

Commercial indicating wattmeters are practically confined to two types, the induction and electrodynamometer types. Of these, the latter is much the preferable type, as it may be used with equal accuracy on Direct Current and Alternating Current, and is not subject to large frequency errors, consequently it is more readily adapted to meet the varying conditions imposed by modern commercial practice. Weston Wattmeters operate on the electrodynamometer principle, which in the direct reading form was a Weston invention.

Principle of Operation

When current is caused to flow in a conductor there is set up about the conductor and in a plane perpendicular to it, a magnetic field which is proportional to the strength of the current flowing. If two conductors carrying currents are placed near each other but not parallel, the magnetic fields about them will react upon each other in such a manner as to tend to become parallel. The reacting force will be proportional to the fields about the conductors and therefore to the product of the currents in the conductors. The reaction is communicated to the conductors as a force tending to place them in a position parallel to each other.

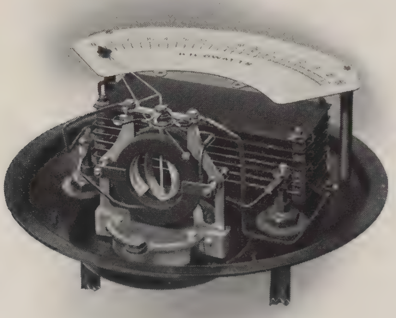
In the Weston Wattmeter the conductors are replaced by the field and movable coils. The field coils are held in a fixed position. The movable coil is pivoted so that its only possible motion is that of rotation. It is placed directly between the two field coils. When current is caused to flow in both the field and movable coil circuits the movable coil will tend to rotate, the tendency being to place itself parallel to the field coil. The force causing this rotational motion is counter-balanced by the mechanical force exerted by two springs attached to the movable coil staff. When a balance of forces occurs the movable coil motion is stopped and the coil retained in its new position until a further change takes place in either the movable coil or field coil currents. By having the pointer attached to the movable coil staff and properly calibrating a scale over which the pointer will move, the instrument can be used for measuring the reaction effect of the coils upon one another.

If in a direct-current circuit the field coils of the Weston Wattmeter are caused to carry the current of the circuit and the movable circuit has impressed upon it the potential of the circuit, the instrument will indicate the product of the value of current and voltage, which is the power or watts expended, since in a direct-current circuit the instantaneous values of the current or voltage are the same for all consecutive periods of time.

In an alternating-current circuit the conditions are slightly different owing to the characteristic possessed by such a circuit, which is known as reactance. Reactance is caused by the presence of inductance or capacity in the circuit.

Instantaneous values of current or voltage are continually changing from a maximum positive to a maximum negative passing through zero and all the intermediate values. This cycle is repeated, the frequency of repetition in a second determining the frequency of the circuit. The process is conveniently pictured by a curve known as a sinusoid. If the circuit is composed of resistance only the current and voltage of sinusoids reach their positive and negative maximum points at the same instant and simultaneously pass through zero. By introducing inductance in the circuit the current curve reaches the maximum at a time later than does the voltage curve, the interval of time depending on the value of the inductance and the frequency of the circuit. This difference in time expressed as an angle is called the phase displacement. Its effect on the power of the circuit is to reduce the value of the power for the same value of current and voltage as compared to the power in a purely resistance circuit. The power is represented by a curve derived by plotting the products of the instantaneous values of current and voltage. The wattmeter indicates the average value of these instantaneous values of power. The actual or true power is equivalent to the product of the volts and amperes multiplied by a factor called the power factor, which is always less than one.

The wattmeter, to indicate correctly on alternating as well as on direct currents, must have the potential circuit practically free from internal inductance. Therefore, great care must be taken in the design of the coils and their relation to one another as well as to the surrounding parts of the instrument so that inductance is eliminated to the very greatest possible extent.



Figue 1

Construction

Having now an idea of the principle of operation of the wattmeter, let us consider the mechanical construction of the Weston Wattmeter. For the sake of simplicity we will consider the Model 167 Single Phase Switchboard Wattmeter as a typical example and subsequently make clear wherein the other models differ from Model 167.

In Figure 1 this model is illustrated with cover removed. In the foreground are the field and movable coils. The field coils are accurately located in position on the coil support by means of the flanges clearly shown in Figure 2. They are securely retained in

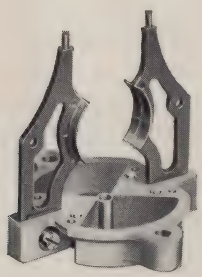
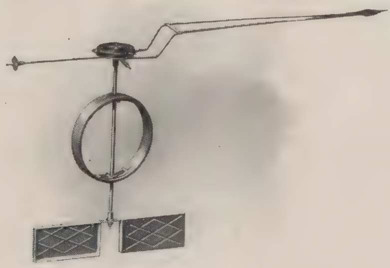


Figure 2

place by means of suitable clamps. The coils consist of a proper number of turns of copper conductor of adequate cross-section as is required to produce the necessary field with the available current and without overheating of the coils. The available current is of course determined by the range of the instrument. The field coils are connected in series or in multiple, depending on the current range of the instrument. Those in Figure 1 are connected in series. Connection of the field coils to the circuit is made through back connection studs, a portion of which can be seen in the illustration. Each turn of the coils as well as the completed coils is insulated to afford protection against short circuit and break down.

The movable coil which is seen to be within the field coils is pictured in detail in Figure 3. The coil is composed of a number of turns of relatively small size insulated wire of good conductivity. Passing through the coil and supporting it by means of two so-called shoes fastened to the coil, is a staff of aluminum alloy. In the ends of the staff are the pivots which support the movable system in the jewels.

At the lower extremity of the staff are the air damper vanes which move in the air damper chamber shown in the base of the



Figue 3

coil support, Figure 2. These damper vanes must be very accurate as to dimensions and alignment to avoid rubbing on the walls of the damper chamber, the clearance being small to achieve effective damping of the movable coil motion. In Figure 1 the damper box is shown with its cover in place.

At the upper extremity of the staff are mounted the pointer and springs. The pointer consists of a hollow aluminum alloy tubing provided with a proper tip and tail and balance cross arms. The tail and cross arms are not tubular. They are threaded with a thread of very fine pitch on which balance nuts are placed. The pointer is very accurately balanced by means of these nuts so that its weight may not cause it to deviate appreciably from its normal position no matter in what position the instrument may be placed. It will be noticed that the pointer is braced at a point just forward of the upper bend. This bracing makes the natural vibration period of the pointer to be outside of the frequency limits of the instrument so that the pointer will not get into resonant vibration on any commercial frequency.

The instrument is provided with two springs as shown in Figure 3, attached to the staff just above the pointer. These springs serve the double purpose of controlling the degree of deflection of the movable coil and acting as conductors for carrying current into and out from the movable coil winding.

It can readily be appreciated that the weight of the movable system is as light as can be mechanically obtained while retaining adequate strength. This is essential in prolonging the life of the instrument. The mass of the system is carried as near to its axis of rotation as is possible, and this combined with light weight, imparts the characteristic of responsiveness for which Weston instruments are noted.

The resistance shown in the form of flat sheets placed under the scale plate in Figure 1 is connected in series with the movable coil. It is adjusted to permit the proper value of current to flow in the movable coil. These sheets are free from inductance and capacitance. They are spaced a proper distance apart so that they can readily dissipate the heat produced in them by the current flowing in them.

A glance at the scale of Figure 1 will show it to be practically uniformly divided. The ordinary wattmeter scale is not so, the divisions at the center being nearly uniform, but those at the end being of decreasing widths. The uniform scale is an important feature, as it permits of equal accuracy of scale reading at any part of the scale. To obtain this feature in the Weston Wattmeter particular attention was given to the dimensions of the field and movable coils, their relation to one another, and the position of the pointer with respect to the movable coil. It was found that the pointer should lead the movable coil by a certain definite amount in order to procure a scale having the best characteristics.

Reference has been made to the disposition of the parts adjacent to the movable and field coils. Such a part is the field coil support. An examination of Figures 2 and 6 will show how the metal has been disposed of to retain mechanical strength and yet produce a path of high resistance to such currents as would be generated in the support by the magnetic field produced by the field coils. The material used is a special alloy having a high resistivity. Currents which would otherwise circulate in these metallic parts would cause an internal phase displacement which is very undesirable.

The working parts of the instrument are contained within a

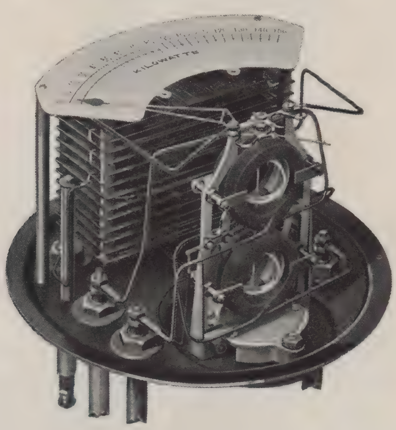


Figure 4

drawn steel case which not only affords mechanical protection, but also protects against the effect of stray or external magnetic and electrostatic influences.

The zero corrector is placed in the top of the case. It consists of a small slotted head which when turned actuates the zero adjuster fork shown just above the springs in Figure 1. By means of this device any deviation of the pointer from its normal zero position is quickly corrected.

Thus far our remarks have been more particularly in reference to Model 167 Wattmeters. As the Weston Company produces wattmeters other than Model 167, we will call attention, briefly, to the important differences in construction.

In Figure 4 is illustrated the Model 216 Polyphase Wattmeter, which, it will be noticed, is virtually two separate wattmeters which are mechanically connected to employ one pointer moving across one scale. Figure 5 shows the movable coils, two in number,

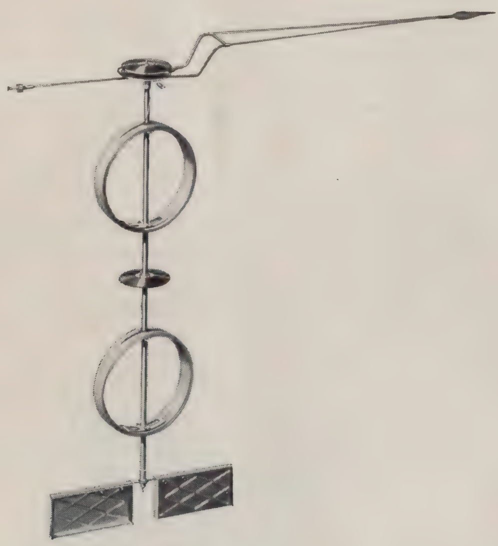


Figure 5

fastened to the same staff. Thus the reaction effect of each set of field coils on the corresponding movable coil is communicated to the staff and pointer, a deflection resulting which is caused by either the sum or difference in the individual forces as the case may be, depending on the electrical condition of the external circuit.

An examination of Figure 5 discloses three springs. One of the upper springs is common to the two coils. This is the usual

construction. Under certain conditions it is required that the coils be entirely remote or insulated from one another, in which case four springs are provided, the third and fourth springs being placed between the two coils. This form of construction is used for two-phase four-wire instruments. The Model 343 Single Phase and Model 368 Polyphase Wattmeters do not differ materially from the larger size models just described. The pointers are necessarily shorter in length and in the Model 368, because of lack of space within the instrument case, all of the potential circuit resistance is contained in an external box.

In Figure 6 is illustrated the coil support and damper box for the polyphase wattmeters.

Figure 6

The Model 310 and 329 Portable Wattmeters and the Model 326 Laboratory Standard Wattmeter, although composed of generally similar parts as are used in the switchboard instruments, present several distinct and interesting differences in construction.

These instruments are provided with knife edge pointers and scale plates having mirror slots to enable accurate readings to be obtained. The steel case of the switchboard instruments is replaced by a hardwood box, the shielding effect of the steel case being obtained through the use of a laminated iron shield which completely surrounds the movable coil and field coil systems. This is

shown in the section view of the Model 310 Wattmeter, Figure 7. An outer steel shell or cup affords mechanical protection and supports the vital parts of the instrument.

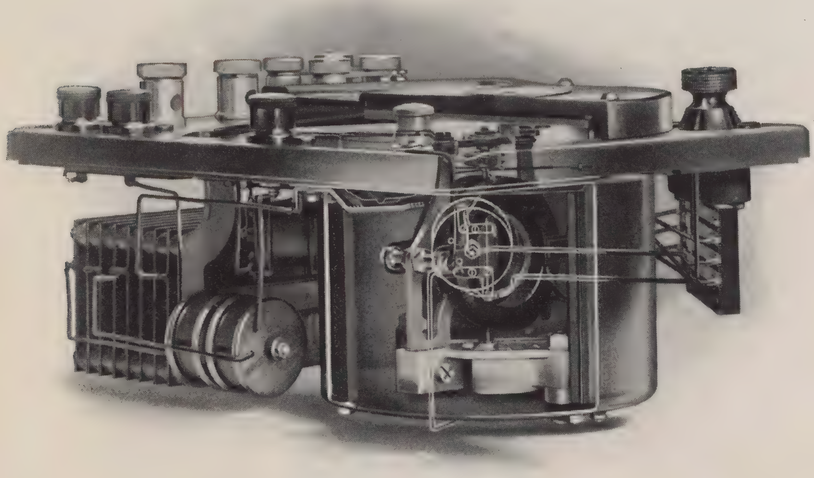


Figure 7

In the Model 310, 329 and 326 instruments the sections of the field coils are arranged to be connected in series or multiple, affording a double current range. The potential circuits are provided with a switching device permitting opening and closing of the circuit at will. This feature is omitted in the Model 310 Form 2 Wattmeter, for use on low power factors, being replaced by a compensating switch, to which further reference will be made. In Models 310 and 326 the switching device is in the form of a contact key. In the Model 329 it is a rotary switch which simultaneously operates on the potential circuits of the two phases. All Model 310 instruments have a reversing switch used to change the direction of current flow through the movable coil in case the polarity happens to be incorrect and the pointer deflects below the zero mark instead of up the scale.

In the Model 329 Polyphase Wattmeter each phase is independent of the other. A four-spring movable system is required. The field coils are adjustable with respect to the distance they are spaced apart by means of which each phase is made to have the same scale characteristics as when both phases are used together. This is essential when using the instrument on unbalanced polyphase circuits or on power factors which are very low. Precaution has also been taken to avoid the action of one set of field coils on the movable coil belonging to the other set. This has been accom-

plished by placing a laminated iron shield between the upper and lower systems.

Characteristics

Let us now consider some of the electrical characteristics of these wattmeters. Temperature errors in switchboard instruments are not compensated for, but such errors as will occur in practice are small and well within the guaranteed accuracy of the instrument. The Model 310 Form 1 is exactly compensated for errors due to changes in temperature. The Forms 2 and 3 are not compensated. This is for specific reasons, which will be brought out in the next paragraph. However, in these instruments the errors in indications due to temperature changes are small and only for the highest precision need they be taken into account. This same argument applies to Model 329. Model 326 Laboratory Standard Wattmeters are exactly compensated for temperature errors.

The introduction of the temperature compensating device in the Model 310 Form 1 has the effect of reducing the range of frequency over which the instrument can be used without errors being introduced in the indications because of the varying frequency. In the Form 1 instrument the highest frequency is 133 cycles per second. Above this value it is necessary to apply a correction factor if the accuracy is to be maintained within the guarantee. The Form 2 instrument, although not compensated for temperature and therefore not subject to the limitation imposed by the compensating device, is a very special instrument which will hardly ever be used on frequencies in excess of 133 cycles per second and hence this is given as the high value of frequency for that particular instrument. The Form 3 instrument can be used at very much higher frequencies without incurring errors exceeding the guarantee. At unity power factor, instruments having voltage ranges above 100 volts can be used on frequencies as high as 1200 cycles per second. These are intended for use on Alternating Current circuits of radio spark sets which are usually of 500 cycles frequency but they are equally good on circuits of lower frequency and on direct current circuits. Model 326 Wattmeters are compensated for errors due to changes in frequency but owing to the very high degree of accuracy required of them the high value of frequency has been placed at 133 cycles per second. This high value can be varied for particular instruments if so specified at the time of ordering so that the proper adjustment can be made at the time of manufacture.

The field coils in all Weston Wattmeters, except those used in the Model 310 Form 2 instruments, will stand a continuous overload of 100 per cent., that is, they will carry, without overheating, twice the normal current for which they are intended. The potential circuits are also designed to send a liberal overload voltage but this overload value varies with the range.

The allowable values are given in the price lists for this type of instrument which appear in the several bulletins and catalogs which the Weston Company has issued. In the Model 310 Form 2 Wattmeter we have an instrument in which the voltampere capacity is relatively large as compared to the watt range. This condition is accomplished by working both the potential and current circuits at their maximum carrying capacities so that in this instrument there is no overload characteristic.

A feature possessed only by the Form 2 Wattmeter is that of being compensated for the power taken by the potential circuit which would otherwise be included in the instrument indication. The compensation is accomplished by a compensating coil wound turn for turn with the winding of the field coils. The current required by the potential circuit passes through the field coils adding to the intensity of the fields which tends to increase the indication by the power lost in the potential circuit. This current is caused to flow through the compensating coil but in a direction opposite to the direction of the field current because of which it exercises a demagnetizing action on the field which exactly neutralizes the increased field which it caused while flowing in the field coils. Thus the instrument indication is that which represents the power of the external circuit only. This feature is a necessity on low reading wattmeters if accuracy of reading is required.

Since in these wattmeters the field coils are connected either in series or multiple, depending on the range to be used, it is necessary that the compensating coils be similarly connected otherwise the compensation would not be accurate. This is accomplished by means of a rotary switch which can be set so that the actions of the compensating windings can be connected in series or in multiple. A third position is also provided at which the compensating winding is disconnected. This position is known as the "Uncompensated" position and must be used when the wattmeter is employed in conjunction with either current or potential transformers and when comparing wattmeters.

Choice of Wattmeters

For switchboard practice the size of instrument selected will depend on the switchboard and the space available for instruments. The range will be such as to permit a reasonable overload capacity. Under normal conditions the pointer should be from 75 to 80 per cent. up the scale. Whether the instrument is direct connected or connected through external resistors or transformers will depend on the current and voltage requirements of the circuit. In deciding this question the information given in our catalogs should be taken as a guide. When ordering wattmeters the line voltage, line current, number of phases, current and potential transformer ratios, frequency and the scale in kilowatts should be stated.

When selecting a portable wattmeter thought should be given to future needs as well as to the immediate need. Thus while the immediate need may call for an instrument of 30 ampere capacity, it might be economy to purchase a 2.5-5 ampere instrument and a Model 312 Current Transformer of 25-50-100 amperes range. With such a selection the outfit becomes more flexible and eliminates the necessity of purchasing instruments of other ranges for future requirements, it only being necessary in certain cases to purchase a relatively inexpensive auxiliary which will enable the particular need to be met. The same reasoning applies in the case of the potential range, the Model 311 Potential Transformer being employed in conjunction with a 75-150 volt instrument.

Laboratory Standard Instruments present the same general problem with the added argument in favor of the use of auxiliaries in that the cost of these standard instruments is very much higher than is the cost of the average portable instrument. Laboratory Standards must be selected with regard to future requirements unless very great expense is to be involved.

Electrodynamometer Ammeters and Voltmeters

In the Weston Electrodynamometer Ammeters and Voltmeters the mechanical details of the field coil support, the means for damping, the pointers, the shielding and the type of construction of the movable coil and field coils are similar to those of the wattmeter previously described. It will therefore be our purpose now to explain the special characteristics, including special constructional features, of the ammeter and voltmeter.

The Ammeter

In the group of electrodynamometer ammeters are included the Model 370, having ranges of 1 ampere and higher, and the Model 326 Laboratory Standard Ammeter. (Model 370 instruments having ranges below 1 ampere are classed as a milliammeter. They will be mentioned later.)

The Model 370 Ammeter has two field coils which should be connected in series when the low range is to be used and in parallel when the high range is to be used. These field coils are of a medium size conductor with a relatively small number of turns, similar to those used in the wattmeter. The change in connection is made by means of two links located on the top of the instrument. A resistance of proper value is connected in series with the field coils. This resistance is called a shunt. It is so designed that it is possible to utilize the entire resistance or only a certain portion of it. When the field coils are arranged for low range readings the entire shunt is used; for high range readings only a portion of the shunt is brought into use. Marked binding posts on the instrument top connect to the proper portions of the shunt.

The movable coil circuit is connected across the complete shunt and obtains its current from the drop produced by the current to be measured. The current to be measured passes through the field coils and through the parallel circuit consisting of the shunt and movable coil circuit.

The instrument operation depends upon the reaction produced between the field and movable coil currents. The movable coil current being proportional to the shunt drop, which is in turn proportional to the current to be measured, the torque of the instrument is proportional at any point of the scale to the square of the current flowing. Consequently the instrument indicates the true effective value of the current.

It is therefore essential that the current passing through the movable coil be the same for full scale values of current applied to the instrument for both high and low ranges. This condition is achieved by making the resistance of the two portions of the shunt exactly the same.

By properly designing the various parts of the instrument and correctly relating them to one another, an instrument has been

produced which is practically free from temperature errors, working errors and frequency errors for frequencies as high as 133 cycles per second. With special compensation the frequency limit can be made as high as 1,000 cycles per second.

The Model 326 Laboratory Standard Ammeter is in general similar to the Model 370 as far as operation is concerned. It differs however in important details. The links of Model 370 used for changing the field coils from series to parallel connection, or *vice versa,* are replaced by a plug switch. The shunts in the field coil circuit are distinctive units and hence independent of each other, the one for the low range being twice the resistance of the high range shunt. Also the movable coil circuit, instead of being permanently connected across the ends of a shunt as in Model 370, is capable of being connected across each shunt unit. This is accomplished by means of a plug switch. The shunts are properly connected in circuit by means of binding posts as in Model 370.

To attain the very high degree of accuracy of the Model 326, the movable coil circuit is provided with a compensating shunt resistance which eliminates all effect of temperature change, and the effect of change in frequency is eliminated by compensating for the self-inductance of the movable coil by means of a condenser shunting a portion of the resistance of the movable coil circuit. Although this compensation is used, the frequency limit is conservatively given as 133 cycles per second to provide for bad wave form. Special adjustment is made for higher frequencies up to 600 cycles per second.

Models 370 and 326 Ammeters may be used on both direct currents and alternating currents with equal accuracy.

All these instruments have double ranges, the higher range being twice the low range value. The combinations are 1-2, 2.5-5 and 5-10 amperes. The ranges may be extended by means of current transformers of proper accuracy used with an instrument having a 5 ampere range.

The Model 370 Milliammeter, which includes all ranges below 1 ampere, has no shunt, but has its movable and field coils connected in series, the current to be measured passing through both. It is only made as a single range instrument.

In consequence of the fact that the field and movable coils are connected in series, both carrying the full current to be measured, the milliammeters can be used on frequencies as high as 1,000 cycles per second without exceeding the guaranteed accuracy.

The Voltmeter

Both the Model 341 and the Model 326 Voltmeters are also electrodynamometer instruments. In this form of voltmeter the field coils are wound with many turns of a smaller size wire than is used in the ammeters. The field and movable coils are connected in series so that the full current required to operate the

instrument passes through both. This current is comparatively small, varying with the range of the instrument, the lower the range the larger the current required by the instrument. Thus for example a 1-volt instrument requires about 500 milliamperes and a 750-volt instrument about 30 milliamperes. Of course the coil windings, both as to conductor size and turns, will also depend on the range. For this reason double range instruments can be made only in certain combinations. These combinations are given in our several catalogs and need not be further considered here.

An exception to the above statement exists in the Model 326 Voltmeter, which is only made as a three range instrument, the ranges being 75-150-300 volts, which are of high resistance and consequently require a small current for operation.

Care must be exercised in the use of Model 341 Voltmeters of low range, as the current required to operate them may cause a change in the normal condition of the circuit on which the instrument is used. To obviate this to the fullest extent, thereby obtaining as high an accuracy of voltage measurement as is possible, the instrument current has been kept as low as design would permit.

For ranges below 75 volts the current of operation must be given careful consideration when selecting an instrument.

Model 341 Voltmeters are capable of being used on direct-current circuits or on alternating-current circuits of any frequency as high as 133 cycles per second without exceeding the limits of the guaranteed accuracy. When specially adjusted, the frequency limit can be extended to 600 cycles per second.

Single range instruments of ranges as low as 10 volts are practically uninfluenced by changes in room temperature. Double range instruments of 150-75 volts and higher have a negligible temperature error. On other double range instruments the higher range is not materially affected, but the lower range will have a slight error, which can be corrected for as explained on the instrument certificate. These errors, however, are exceedingly small and may be neglected in most measurements.

Working error is the error caused by the instrument parts becoming heated by the instrument current as the instrument is left in circuit. Only in instruments of ranges lower than 7.5 volts does this error assume any appreciable value. The maximum error is about ⅕ of 1 per cent.

The Model 326 Voltmeter is compensated for temperature changes and for errors due to changes in frequency. Because of the high degree of accuracy required of these Model 326 Voltmeters the maximum frequency limit has been set at 133 cycles per second. They can, however, be used on higher frequencies if the wave form of the alternating current does not contain other

than the fundamental frequency, that is if it is a sinusoidal wave. With a special adjustment the frequency value can be increased to 600 cycles per second.

The resistance of any range of the Model 326 Voltmeter is so high that its introduction into the circuit will not ordinarily disturb the circuit condition by any appreciable amount.

Ranges of voltmeters can be extended by using external multipliers or resistances, or potential transformers in conjunction with an instrument having a 150-volt range.

Weston Movable-Iron or Electromagnetic Instruments

At the time Dr. Weston was developing a reliable direct-current instrument one of the possibilities considered was the movable-iron or electromagnetic type. He finally decided upon the permanent magnet type because it is the best for direct-current instruments. However, he did not overlook the fact that the electromagnetic type could be made up as a cheaper and simpler form of instrument which would be just as durable although less accurate and fill requirements where the permanent magnet type would be too expensive.

After introducing the permanent magnet instrument, Dr. Weston developed a switchboard instrument operating on the electromagnetic principle. These instruments were not satisfactory because they were not representative of Weston quality, although they were superior to any of the instruments of the electromagnetic type then obtainable. For this reason they were not put on the market. Dr. Weston then entered upon a period of research extending over a number of years. During this research new materials were produced, new laws were formulated and many electrical and mechanical factors co-ordinated. One result of all

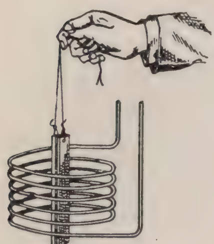


FIG I

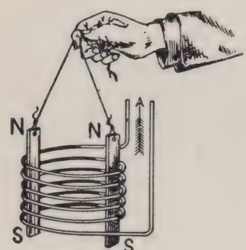


FIG 2

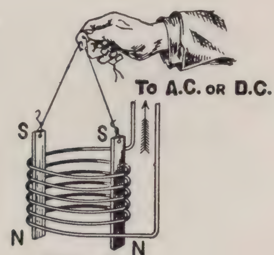


FIG 3

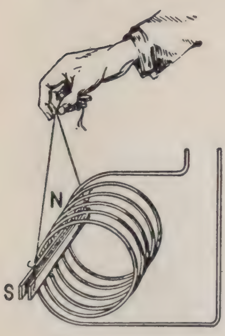


FIG 4

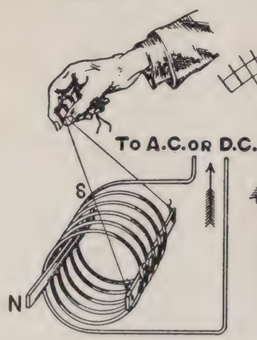


FIG 5

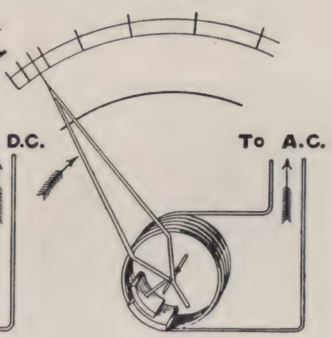


FIG 6

this was that in 1907 the first practical and successful electromagnetic instruments were placed on the market.

The principle of operation of this type of instrument will be easily understood by referring to Figures 1 to 6 and the following explanation.

In figure 1 we have two pieces of soft iron suspended vertically in a coil or solenoid by means of threads. There being no current flowing there will be no action between the iron pieces. Figure 2 shows the effect of passing a direct current through the coil. The direction of flow is such that the upper ends of the iron pieces are magnetized to be N poles and the lower ends S poles. Since like poles of two magnetized bodies will repel one another, the iron pieces are forced apart. Figure 3 shows the same action but with the current reversed. If this reversal is sufficiently rapid the iron pieces will remain apart until the current flow is stopped. Figure 4 illustrates the coil horizontally placed with one iron piece fastened so that it cannot move while the other piece is free to move. Figure 5 shows the effect on this arrangement when current flows. In Figure 6 the movable-iron piece is attached so that it can only move by rotation. Thus when current is passed through the coil the movable piece will rotate on its staff and the pointer attached to it will move over the scale. This is virtually the manner in which the electromagnetic principle is applied in the Weston Instrument.

Rotation of the movable-iron piece is opposed by a helical spring. The force causing rotation depends on the strength of the magnetic field set up by the coil or solenoid. The field strength depends on the current flowing. Thus when current flows through the coil the movable-iron piece will rotate to such a position where the rotation force and spring force become equal. Motion then stops and the pointer position shows the scale value for the current flowing.

In an ammeter the current passes through a relatively heavy conductor in the form of a coil. The size of this conductor and the number of turns in the coil depend on the current range of the instrument. In a voltmeter a large number of turns of comparatively small wire makes up the coil. In order that the low resistance of the coil might not permit an excessive current to flow when the instrument is connected to the circuit, a resistance is placed in series with the coil so that the current flowing through it is reduced to the required value.

Figure 7 shows the ammeter construction, Figure 8 the voltmeter construction and Figure 9 the parts of a Model 155 Ammeter spread out.

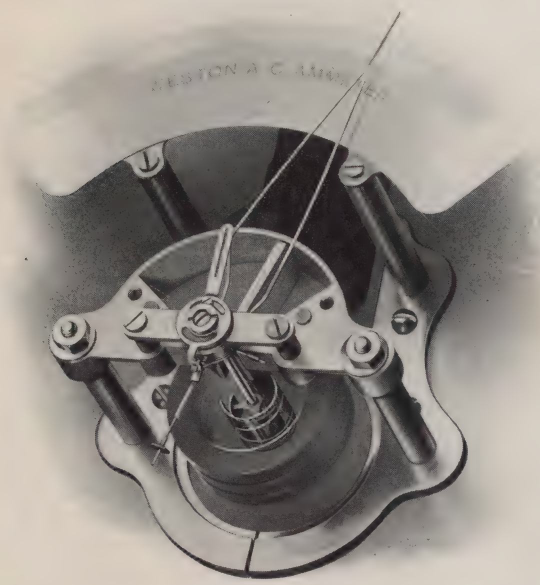


Figure 7

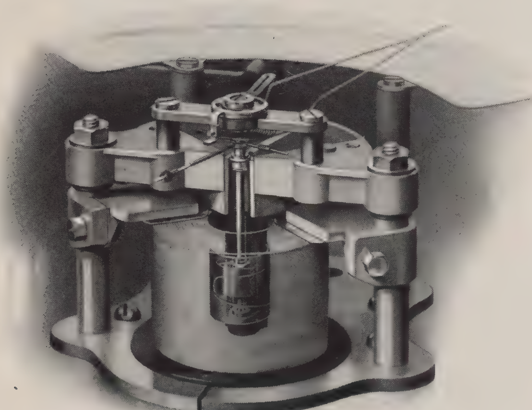


Figure 8

Thus in Figure 9 (3) is the coil or solenoid; (8) is the movable-iron piece attached to the pointer having the air-damper vane and controlling spring in place. Notice that the movable-iron piece is circular in shape.

Figure 9

The relation of the fixed and movable pieces of iron is shown in Figure 7. The fixed piece is secured to the extension in (5) of Figure 9. It is triangular in shape and is bent to be concentric with the movable piece. The uniformity of the scale depends on the shape of this fixed piece.

By referring to Figure 7 the principle of the air-damper is easily understood. This picture shows the damper box cover removed.

The staff supporting the movable-iron rotates in jewels, thus eliminating friction and together with the exceedingly light weight of the movable parts, assuring long life to the instrument. The total weight of the movable system is only about 1.6 grams.

This type of instrument will operate on either direct or alternating current, but it is more accurate on alternating current.

Weston Instruments of this type are made for measuring cur-

rents from 75 milliamperes up to and including 500 amperes and for voltages from 30 to 750 volts. These ranges may be extended by using the customary current and potential transformers and multipliers.

They are also made as portable or switchboard instruments.

Frequency changes affect the readings on voltmeters and milliammeters and low range ammeters to some extent but in general the instrument accuracy is well within its guarantee for any commercial frequency except those used in radio communication. For use on such frequencies special adjustment and calibration is necessary.

These instruments may be left in circuit indefinitely without error resulting but portable voltmeters are provided with contact keys so that they can be connected to the circuit or disconnected at will.

The power consumption is small. An idea of the magnitude can be obtained from the following examples. The power taken by a voltmeter of 150 volts range operating at 110 volts is 6.2 watts. For an ammeter of 5-amperes range operating at full capacity it is 1.1 watts.

Switchboard instruments are contained in either cast iron or drawn steel cases which protect them from the action of external fields.

Weston Thermo Ammeters

Description

The accompanying drawings illustrate the usual forms of external heating elements which form part of the Weston Thermo Ammeter.

Figures 1 and 2 represent the form of element for ranges up to and including 50 amperes.

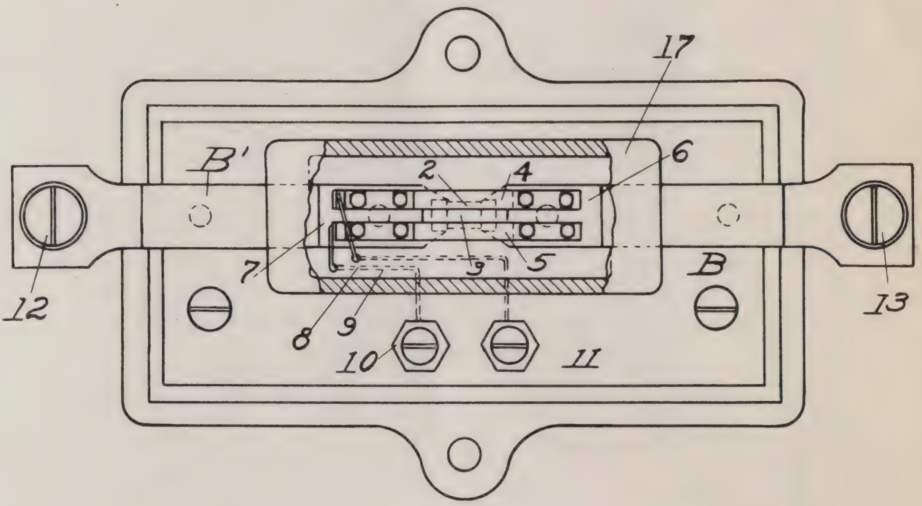


Figure 1

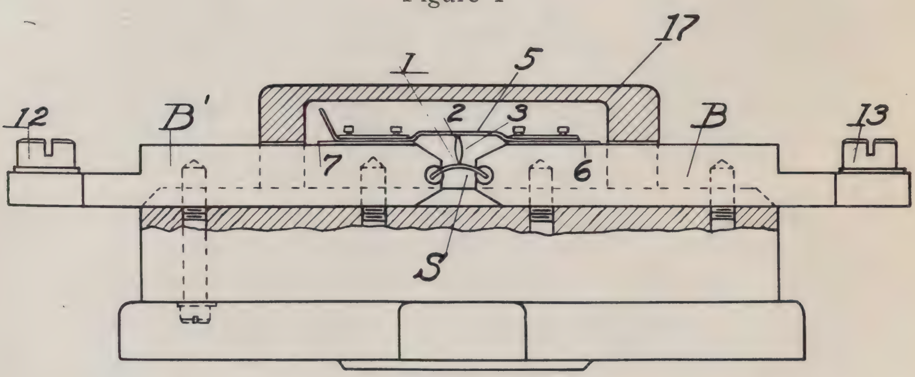


Figure 2

In these figures (S) is a resistor strip consisting of a platinum alloy, hard soldered to the terminals (B) and (B′). This strip carries the current which is to be measured. It is slightly curved to provide for the expansion occurring through becoming

heated. The hot junction of a thermocouple is hard soldered or welded to the strip (S) at its center point shown at (1) in Figure 2. The cold ends of the thermocouple are soldered to the center points (2) and (3) of two copper compensating strips (4) and (5) which bridges across the two terminals (B) and (B′). These compensating strips are electrically insulated from the terminals by very thin mica plates (6) and (7). They are bent as shown to allow for expansion and contraction.

The thermocouple consists of a platinum alloy wire and a nickel alloy wire which are very thin and of small mass. They therefore have a very small heat capacity and are quickly responsive to changes in the temperature of the resistor strip and consequently the current flowing in it. The thermocouple is made as short as possible in order that it should have a relatively low electrical resistance.

The resistor strip or heating strip (S) is made to have a uniform cross sectional area. The compensating strips (4) and (5) to which the cold ends of the thermocouple are attached are made of copper. They are so proportioned as to thermal conductivity, length, cross section and superficial area that they will be thermally equivalent to the heating strip (S).

The protecting case (17) encloses the active portion of the element so as to prevent external air currents from affecting the strips unequally.

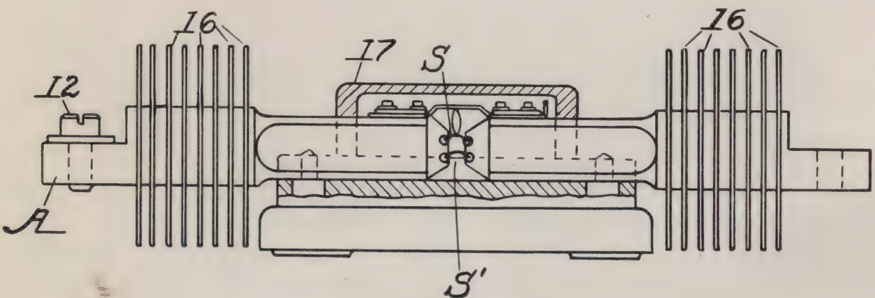


Figure 3

Figure 3 illustrates the form of external heating element used for ranges of from 60 to 100 amperes. The terminals are provided with cooling plates (16) the function of which is merely to carry away any excess heat. It will be noticed that this element has two heating strips to one of which the thermocouple is attached.

Theory

The development of the present form of Weston Heating Elements is based upon the principle that if a conducting strip of uniform cross sectional area, which is carrying current, is cooled

ONLY by conduction through the body of the strip itself and NOT DIRECTLY by the surrounding air, the difference in temperature between the center of the strip and the terminals will be proportional to the square of the current flowing and inversely proportional to the thermal conductivity and specific resistance of the strip material. The temperature difference is therefore a measure of the root mean square of the current flowing.

If no heat is lost by convection to the air and the terminals have equal temperatures, the current can be measured by placing the hot end of a thermocouple at the center of the conducting strip and the cold ends of the thermocouple in thermal contact with the terminals but electrically insulated from them.

In practice the terminals do not in general have equal temperatures and some of the heat is carried away by convection into the air. The convection loss is minimized by making the strip very short so that only a small proportion of the heat is lost directly from the strip into the air. Errors due to differences in the temperatures of the terminals are taken care of by means of a compensating feature.

The compensating feature as manufactured consists of two strips, the ends of which are in thermal contact with, but electrically insulated from the terminals. The insulation consists of very thin mica plates which have relatively good thermal conductivity and are of such size that the respective terminals and ends of the compensating strips have the same temperature at all times.

The compensating strips to which the cold ends of a thermocouple are connected, are so proportioned that they are influenced by the temperature of the air and the difference in temperature of the terminals to the same amount as is the heating strip to which the hot end of the thermocouple is connected.

Consequently, the temperature relation between the hot and cold ends of the thermocouple depends solely upon the effect of the current to be measured and not upon disturbing influences.

Performance

The Weston Thermal Ammeter is intended for the measurement of alternating currents of any frequency but more especially currents of very high frequencies such as are met with in radio and other oscillatory circuits. They are also used for measuring currents of an interrupted character such as are produced by magnetos, spark coils, etc. The indications are not affected by poor wave form.

The heating elements have a safe overload capacity of 50 per cent. The full load drop is only about 150 millivolts which is about one-sixth the drop on a hot-wire expansion type instrument. Very little power is required for operation. The elements are used with indicating instruments having the general characteristic of

damping, permanence of zero, etc., as are possessed by standard Weston Instruments. The combination of instrument and element is not affected by changes in room temperature or by the length of time the combination is in circuit.

Advantages

Briefly, the chief advantages of Weston Thermo Ammeters over the ordinary hot-wire expansion type of instruments are as follows:

Large overload capacity.
Absence of zero shift.
Absence of temperature errors.
Small power consumption.
Responsiveness and dead beat action of pointers.
Permanency and accuracy of indications.
Highest possible standard of workmanship.
Low or entire absence of maintenance costs.
The possibility of mounting the external heating element in the circuit at the most convenient place and the indicating instrument in another place on the switchboard.

Weston Ohmmeter

The Weston Model 1 Type 2 Ohmmeter is a special application of the Weston permanent magnet movable coil type of instrument. In its principle of operation it is distinctly different from any other make of ohmmeter previously or at present existent. (It should not be confused with the previous type of Weston Ohmmeter which required the application of an exact voltage value before using the instrument for measurement.) The instrument is direct reading, the scale being calibrated in ohms.

A notable feature of the Weston Ohmmeter is that it operates on ordinary dry cells without the use of auxiliary controlling resistance or voltmeter for the exact adjustment of the voltage applied. The cumbersome, unwieldy and bothersome storage battery with its constant recharging and necessary supervision is eliminated. From one to six dry cells are required for the operation of this ohmmeter, depending on the range of the instrument. These cells are relatively small and of light weight. They can be readily mounted in a proper container which with the instrument comprises a real portable outfit, ready for use anywhere at a moment's notice. Several units of this kind are constantly in use in the Weston Laboratories.

The Model 1 Type 2 Ohmmeter is made with double or triple ranges. The ranges are quickly changed by means of a plug switch.

Unlike many other forms of ohmmeters, this instrument has no initial spring tension. When the pointer is not indicating it stands in a free zero position. Any inaccuracy in the zero position of the pointer can be instantly corrected by means of a zero adjusting device. With a proper handling of the instrument there need be no slamming of the pointer since the pointer is not under initial spring tension. This is a very decided advantage over other forms of ohmmeters.

This instrument has a guaranteed accuracy of one-quarter of one per cent of full scale value, or better, at any temperature from 10° C (50° F) to 30° C (86° F). It is therefore evident that ordinary variations in temperature have a negligible effect on the accuracy of the indications. Variations in the applied battery voltage, between the time of checking the instrument and using it, produce practically the same per cent of error throughout the scale. A change in applied voltage of one per cent causes approximately one per cent error in the instrument indication. In the more extensively used earlier forms of ohmmeters this was not so. For example, a change in battery voltage of one per cent might cause an error in the indications at the lower portion of the scale of several per cent.

Perhaps the most appealing advantage of this new type of

ohmmeter is that it can be instantly checked against a standard resistance which is contained within the instrument and if found to be in error adjusted to be correct. The adjustment is accomplished by changing the position of a magnetic shunt with respect to the pole pieces of the instrument. By the change in position of the magnetic shunt the intensity of the magnetic field acting upon the movable coil of the instrument is increased or decreased as required. In this way variation in the battery voltage is corrected for. This feature places the instrument on a par, as far as accuracy is concerned, with a voltmeter which may have its top mark checked at any time against a potentiometer.

Another outstanding feature of the Weston Ohmmeter is its simplicity of manipulation. After checking the instrument the resistance to be measured is connected to the binding posts marked (X). The plug is changed from the checking position to one of the measuring positions. The contact key is pressed down and the value of the resistance to be measured is read directly on the scale of the instrument. It is not necessary to check the instrument before every measurement, only occasional checking of the battery voltage being required.

In order that the principle of operation of the ohmmeter may be understood Figures 1 to 10 have been prepared illustrating the internal connections of the double and triple range instruments corresponding to the various plug positions.

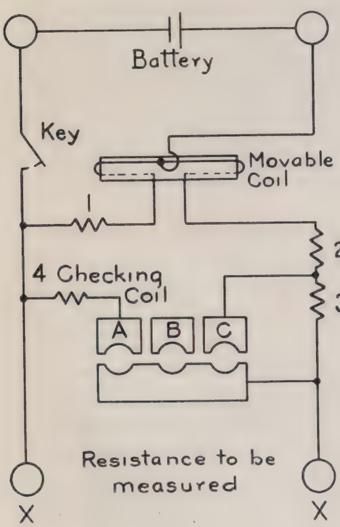


Figure 1
Internal connections

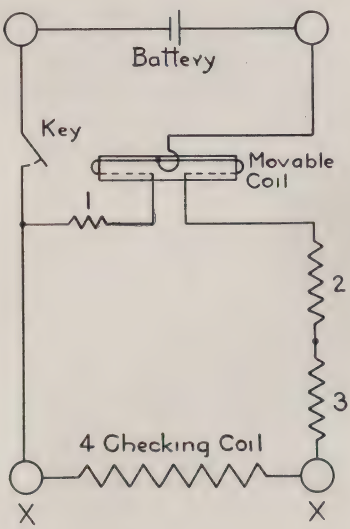


Figure 2
Plug in hole A for checking

Referring to Figure 1, which shows the internal connections of the double range instrument, we find the principal electrical components of the instrument to be the movable coil and four resistances. The movable coil is differentially wound. The effect of one section of the coil is to deflect the pointer up the scale, and of the other section to deflect the pointer down the scale. When these effects are equal the pointer rests at the zero mark of the scale. This condition is produced in the instrument by having the resistances (1), (2) and (3) of such values that the two sections of the movable coil exactly counteract each other when zero resistance is connected across (XX). Resistance (4) is the checking resistance. It is equal in value to the full scale value of the low range.

When the plug is placed in the checking position (hole A) the internal connections are as shown in Figure 2. Coil (4) is connected to the binding posts (XX), becoming the resistance to be measured. Its value being equal to the full scale value of the low range, the pointer should indicate top mark on the scale, when the contact key is depressed. Any deviation from the top mark position is corrected by means of the magnetic shunt which is controlled from the outside of the instrument.

Having checked the instrument the plug is removed from hole A and placed in hole B if the low range is to be used and in hole C if the high range is to be used. When the plug is removed from hole A the checking coil (4) is removed from the circuit.

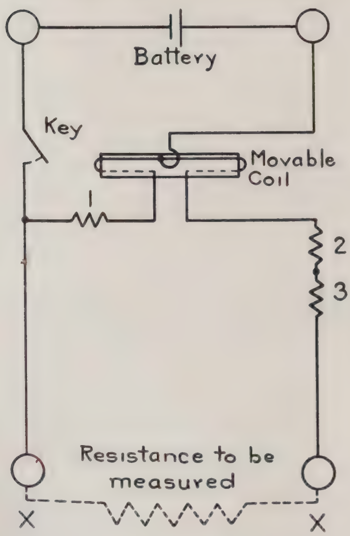


Figure 3
Low range, plug in hole B

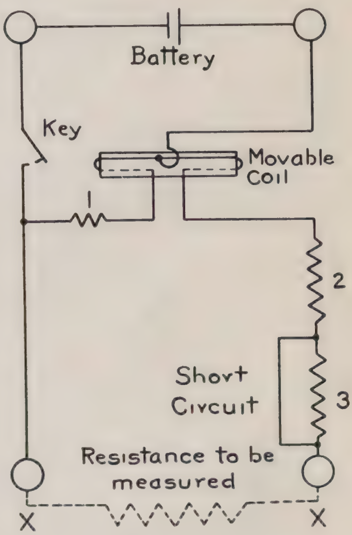


Figure 4
High range, plug in hole C

Figure 3 shows an unknown resistance connected to (XX) the the plug in hole B (Low Range). When the key is depressed the value of the resistance will be directly indicated on the scale.

Figure 4 shows the high range in use. It will be noticed that resistance (3) is short circuited. This resistance has a value equal to the full scale value of the low range. Therefore when the key is depressed the effect of that section of the movable coil which tends to deflect the pointer down the scale is increased. Suppose the instrument being used has ranges of 0-100, 100-200 ohms. By putting the plug in hole C Figure 4, 100 ohms have been short circuited. If now 100 ohms is connected across (XX) and the key depressed the indication of the pointer will be 100 on the upper or higher range scale which is the normal zero position of the pointer. The pointer takes this position because the resistance condition is the same as when (XX) has zero resistance across them and resistance (3) is not short circuited under which condition the two sections of the movable coil exactly counteract one another. With increasing resistance applied at (XX) the instrument will indicate up the scale because the downward effect of the movable coil becomes less and the upward effect is unchanged.

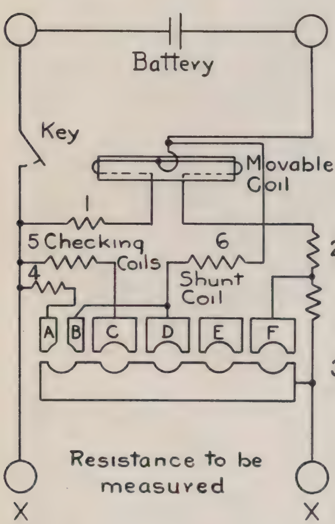


Figure 5
Internal connections

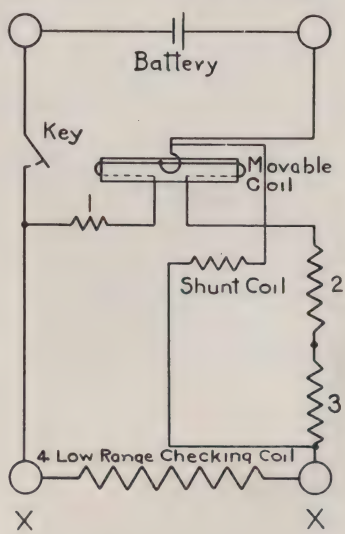


Figure 6
Low range check, plug in hole A-B

In the triple range instrument the low range value is obtained by shunting one section of the movable coil and the resistances in series with it. This shunt is (6) in Figure 5. Because of the

lower resistance a larger current is required to operate the instrument on the low range than on the intermediate and high ranges. This increased current causes a drop in the voltage of the dry cells used. Unless means were provided for correcting for the drop in voltage there would be an error in the results obtained on the low range if the instrument was checked under intermediate or high range conditions. Therefore a separate low range checking coil (4) in Figure 5 has been introduced. Shunt resistance (6) is also in circuit when checking the instrument for use on the low range so that checking voltage and using voltage is the same.

By means of a three point contact A-B Figure 5 the low range checking coil (4) and shunt (6) are simultaneously connected in circuit. Figure 6 shows the low range checking connections and Figure 8 the working connections. It will be noticed that the

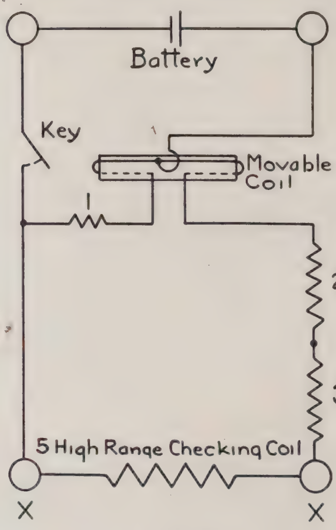


Figure 7
Intermediate and high range check, plug in hole C

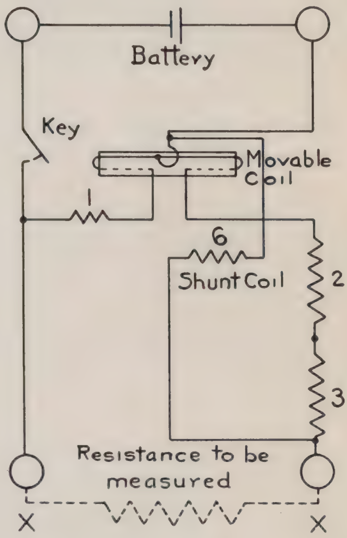


Figure 8
Low range, plug in hole D

plug is placed in hole D and that the shunt (6) is retained in circuit as when checking.

Figure 7 illustrates the connections when the plug is in hole C which is the checking position for the intermediate and high ranges.

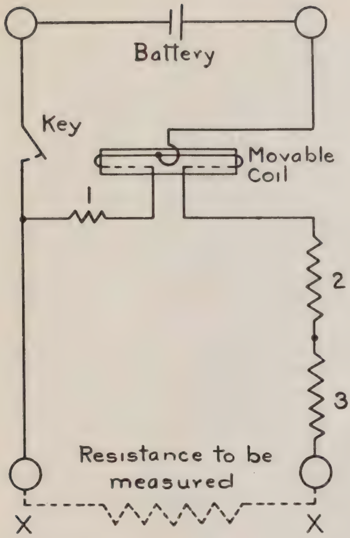


Figure 9
Intermediate range, plug in hole E

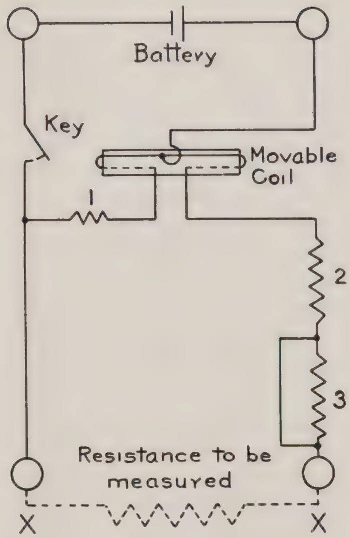


Figure 10
High range, plug in hole F

Figures 9 and 10 show the connections for the intermediate and high ranges when used for measuring resistances. The mode of operation is the same as explained under the double range instrument.

It is important to note that when checking the ohmmeter there must not be any resistance connected to the binding posts (XX).

Its Uses

The Weston Ohmmeter is capable of filling a large need in commercial practice. It is ideal for inspecting for continuity of circuit and value of resistance, electromagnet coils, coils used in telephone and telegraph service, rheostat windings, spark and induction coil windings, watthour meter coils, armatures of magnetos, armatures of small generators and motors, motor and generator fields, resistances used in household heating appliances such as electric stoves, percolators, flat irons, and toasters and for the testing of electrical conductors.

A further use for these ohmmeters is for the approximate adjustment of resistances during manufacturing processes. In the Weston Laboratories they are employed for preliminary adjustments of resistances which are required to be very accurate. The final adjustment is done on a proper bridge. In instances where the accuracy of adjustment need not be better than one-

quarter of one per cent the complete adjustment of the coil is made with the ohmmeter.

The field of sale for these instruments therefore includes the manufacturer of (1) motors and generators, (2) cables and wires, (3) communication devices, (4) ignition devices, (5) electrical household appliances, (6) watthour meters, (7) general electrical products.

The Central Stations can also make use of the ohmmeter to very good advantage for testing arc lamp coils and for inspecting electrical apparatus about the plant.

Selection of Ranges

In order to get the best results from these instruments the ranges selected should be those best suited for the work to be done. If however this covers a very wide range of resistances it is well to select two instruments which will accommodate the extreme values. This can usually be accomplished by using two triple-range instruments having ranges of 0-10, 0-50, 50-100 and 0-200, 0-1,000, 1,000-2,000 or 0-300, 0-1,500, 1,500-3,000 ohms respectively.

The Weston Synchroscope

In power plant operation it is the general practice to employ a number of generators connected to the same common bus-bars. Load demands are met by using a greater or less number of generators, which when connected in this manner are operating in parallel.

When connecting generators in parallel certain conditions must be observed. In the case of direct current generators the respective polarities and voltages of the machines must be the same. These conditions are readily determined by means of a suitable voltmeter. In the case of alternating current generators the problem is not so simple. In this instance the voltages must be correct; the frequencies must be alike; the generators must have the proper phase relationship and the direction of phase rotation must be the same if polyphase machines are used.

To bring the voltages in agreement merely requires the use of a good voltmeter. The direction of phase rotation is taken care of at the time of installing the generators and need not be further considered. Thus frequency and phase relation remain to be dealt with.

There are two ways in which these conditions are controlled (1) by the use of synchronizing lamps, and (2) by means of synchronism indicators. The latter means is generally used as more satisfactory results are obtained because of the greater sensitivity of the indicators as compared to the lamps.

In the class of synchronism indicators there are two principal forms; the rotating form, and what may be termed the indicating form typical of which is the Weston Synchroscope.

The rotating form is a miniature motor the rotor of which carries a pointer. The direction of rotation indicates whether the incoming machine is fast or slow. The position of the pointer indicates the phase displacement between the electromotive forces when the frequency is right. In these instruments the friction is very large, due to the heavy weight of the moving system, the sliding contacts, the brakes, etc., resulting in a jerky and uncertain motion of the pointer. Rotating synchroscopes such as are now available cannot be considered as reliable devices.

The Weston Synchroscope has none of the disadvantages of the rotating form. It is a special application of the Weston switchboard wattmeter and embodies all of the general features of design and construction possessed by the wattmeter. Of course the movable coil and field coils are specially constructed to render the particular service demanded from a synchroscope. Both

are wound with fine wire. The springs, coil supports, jewels, bridges, pointer, air damper, etc., are all counterparts of those used in the wattmeter. By referring to Figures 1 and 2 the similarity is quite evident. The instrument is further provided

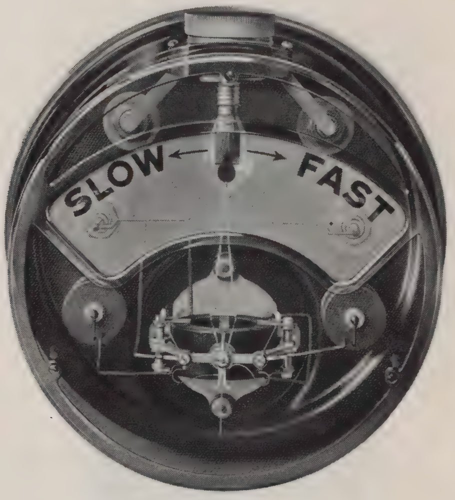


Figure 1

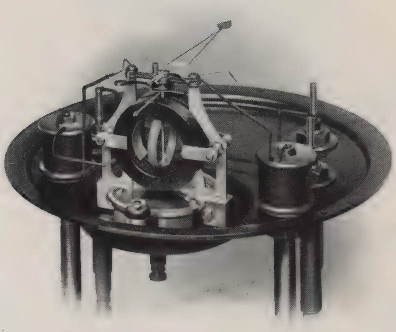


Figure 2

with a translucent scale glass behind which the pointer moves. The scale glass is illuminated from behind the pointer by means of a synchronizing lamp which has its full brilliancy when the

electromotive forces of the machines being synchronized are in proper relation to one another. Figures 1 and 3 clearly show the arrangement.

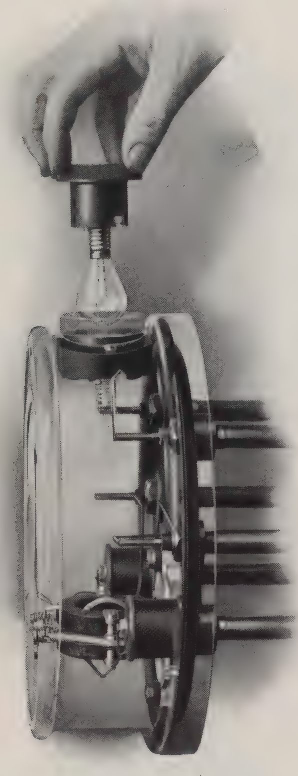


Figure 3

The movable coil is connected through a condenser across the incoming machine. (See Figure 4.) The field coils are connected across the bus-bar through a resistor. Since the field coil circuit has a slight inductance and the movable coil circuit contains a condenser, these circuits can be adjusted so that their currents will be in exact quadrature or 90° out of phase with each other, when the electromotive forces producing the currents are either in phase or in phase opposition (180° out of phase). Under these conditions the torque exerted upon the movable coil is zero and the pointer will stand in its normal position which is

at the center of the black mark on the scale glass. The image of the pointer may or may not be seen depending on whether the electromotive forces are in phase or in phase opposition.

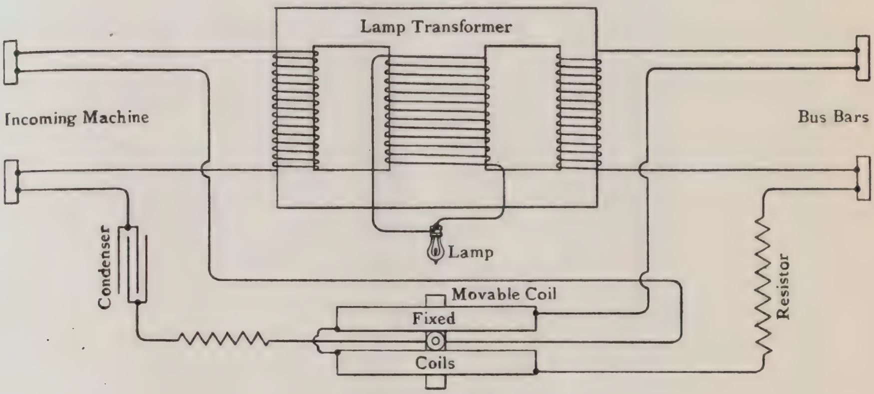


Figure 4

The synchronizing lamp operates at a low voltage from the secondary of a three-legged transformer having two primary windings, one across the incoming machine and the other across the bus-bars. (See Figure 4 and T in Figure 5.) When the

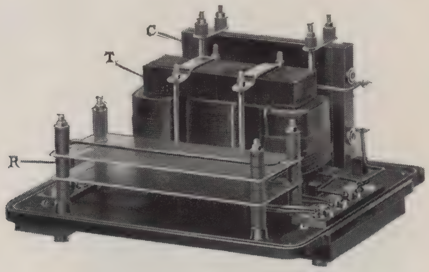


Figure 5

electromotive forces of the incoming machine and the bus-bars are in phase the effect of the primary windings is to produce a maximum voltage in the secondary causing the lamp to be at its full brilliancy. If the electromotive forces are in phase opposition there will be no secondary voltage and the lamp will be dark.

For intermediate phase relations the lamp operates at correspondingly reduced brilliancy. Thus it is readily seen that for exact phase agreement at the proper frequency, the pointer image will be seen at the center of the black spot on the scale, the light

being brilliant. Hence there is no probability of coupling machines in parallel until they are in synchronism.

When the electromotive forces are not exactly in phase or in phase opposition a torque or force will be produced by the action of the movable coil and field coil currents on one another causing the movable coil and consequently the pointer, to turn. The torque is a maximum when the electromotive forces are in quadrature. The direction of the torque is dependent upon the relative directions of the currents in the movable and field coils. If the machines to be connected in parallel are running at the same frequency the pointer will take up a steady position to the right or left of the normal position depending on the degree of phase displacement between the electromotive forces. If the frequencies are not the same, the phase displacement will continuously pass through a cycle of values causing a corresponding cycle of variation in the torque from positive to negative maximums with the result that the pointer will move back and forth over the scale from one extremity to the other. While this is going on, the synchronizing lamp is passing through a cycle of brilliancy from darkness to full brilliancy and back to darkness. The combined result of pointer motion and variation in light intensity is to produce the effect of a rotation of the pointer. The direction of this apparent rotation indicates whether the incoming machine is running fast or slow and the speed of apparent rotation is a measure of the difference in frequency of the machines being synchronized.

To sum up, the machines are in true synchronism and running at the same frequency when the pointer is at rest in the center of the black spot and the light is at full brilliancy giving a distinct image of the pointer on the scale glass. At this time the

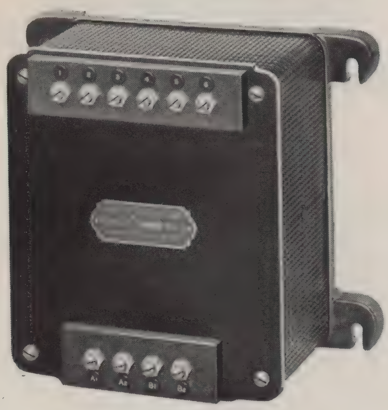


Figure 6

tie switch is closed and adjustment made so that the machines will take their proper proportions of the load.

The lamp transformer, condenser and the greater portion of the resistance of the instrument are contained in the external box shown in Figure 6, which is arranged to be mounted on the rear of the switchboard.

Figure 5 shows the interior arrangement of the box, the sides and bottom having been removed. The condenser is designated C, the transformer T and the resistance R. In Figures 1, 2 and 3 it will be noticed that there are two spools within the instrument itself. These are used for making the resistance adjustments and for adjusting the movable coil and field coil currents to quadrature.

Every detail of the auxiliary box has been given the same careful thought and attention as is usual with all Weston products.

The Weston Synchroscope indicates exact synchronism within 1 degree of true phase coincidence over a wide range of voltage and frequency. The instrument is made with only one voltage range, namely, 100 to 125 volts and it can be used with accuracy on any voltage falling within these limits. For higher circuit voltages it is necessary to use two potential transformers.

As an example of the frequency range it can be stated that a 60 cycle instrument will accurately indicate synchronism at any frequency between the limits of 50 and 70 cycles. The Weston Synchroscope is regularly made for normal frequencies of 25, 40, 50 and 60 cycles.

The power consumption of the Weston Synchroscope is comparatively small, approximately 15 watts being required by each circuit when operating on 110 volts.

In the modern central station equipped with large size and costly generating machinery the synchroscope is a very important piece of apparatus. The large generators must be brought into an extremely close condition of synchronism before they can safely be put in parallel. If this is not done serious damage may be done to the machines or the service to the users of power interrupted.

It is evident, therefore, that the synchroscope shall enable a very fine degree of synchronism to be obtained. This requires that the pointer deflection shall be large for small deviations from synchronism; that the synchroscope shall be reliable at all times; that no disarrangement of circuits within or without the synchroscope shall give an indication which can be construed to represent the condition of synchronism.

A number of synchroscopes have been devised which more

or less meet these conditions but the only one to completely fulfill them is the Weston Synchroscope. Its scale deflection for any deviation from synchronism is the largest obtained in any instrument of its size; it is absolutely reliable at all times and cannot give an indication of synchronism unless that condition actually exists. Any circuit defect whether in the instrument or external to it will be shown in the way the instrument operates which will be either through failure of the lamp to properly light or failure of the pointer to properly move across the scale.

It is conservative to state that the Weston Synchroscope is the ideal instrument for use in paralleling alternating current machines in that perfect control of synchronizing is obtained.

Weston Power Factor Meters

Purpose

The power of a direct-current circuit is expressed by the product of the volts and amperes. In an alternating-current circuit it is necessary to introduce a third factor, known as the power factor, the value of which depends on the circuit and load characteristics. In practice these characteristics cause the current and voltage to be out of phase with one another. The effect of the phase displacement is represented by the power factor.

Power factor, as defined in the Standardization Rules of the American Institute of Electrical Engineers, is the ratio of the actual power in watts to the volt-amperes. In the case of sinusoidal current and voltage the value of the power factor is numerically equal to the cosine of the angle of phase difference.

The importance of keeping the power factor high (its value being equal to 1 if possible, in which case the current and voltage will be in phase) will be appreciated when it is realized that for any given voltage and power the current increases very rapidly as the power factor value becomes less than 1. The increase in current does no useful work but on the contrary results in losses due to the heating effect on conductors, generating machinery and distribution apparatus.

Of course, power factor value can be arrived at by means of computation from the readings of the wattmeter, ammeter and voltmeter. This is time consuming and therefore prohibitive for practical work. What is needed is a means for directly indicating the power factor, and not only its numerical value but also whether the current is leading or lagging behind the voltage. The Weston Power Factor Meter renders just this required service and is an unfailing guide for accurately adjusting power factor when means for doing so, such as the use of rotary converters and static condensers, are available.

Construction

The Weston Power Factor Meter is a special application of the electrodynamometer principle. Mechanically it embodies many of the features of the electrodynamometer instruments previously described. However, it does possess a number of important differences to which we will refer. In Figure 1 we have the complete movement ready for mounting in the case. Notice the elongated shape of the field coils and contrast this shape with the circular form used in the electrodynamometer instruments already des-

cribed. The purpose of shaping the coils in this manner will be explained later.

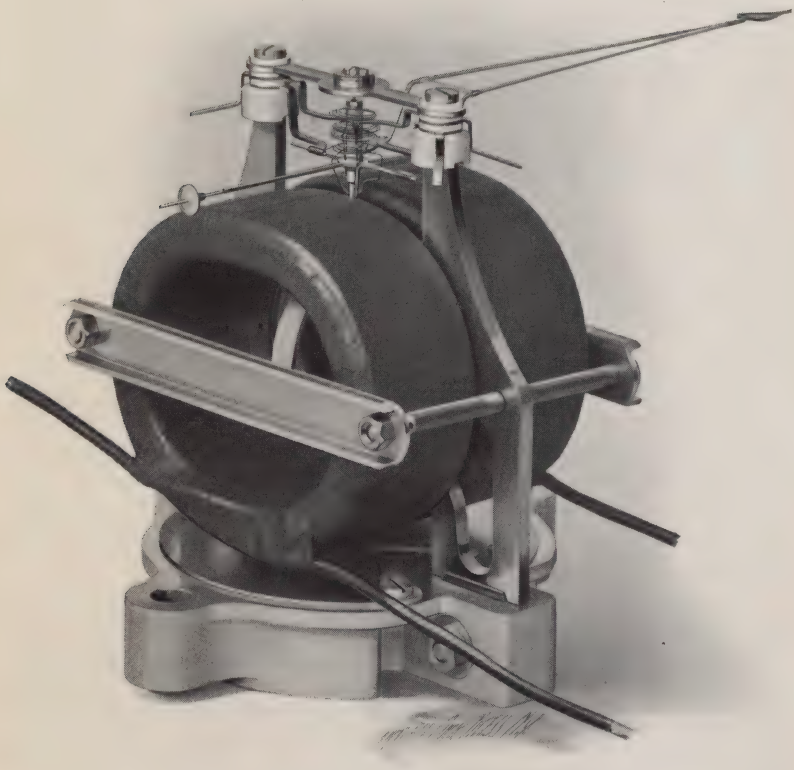


Figure 1

By removing the field coils we have disclosed to view the picture of Figure 2 in which is distinctly shown the movable coil construction. The movable coil consists of two independent coils, similar as to size of wire and number of turns, which are rigidly mounted at right angles to each other. It is exceedingly important that the relative position of these coils to each other should always remain the same. The process of manufacture is such as to assure this condition. The coils are securely fastened to a pivoted staff upon which is mounted the pointer. The relation of the pointer to the coils is not the same for all instruments. For the sake of simplification this matter will be referred to under the discussion of the theory of the instrument.

The ends of the two movable coils are attached to filaments which exert practically no torque but serve the single purpose of conducting current into and out from the coils. The filaments are

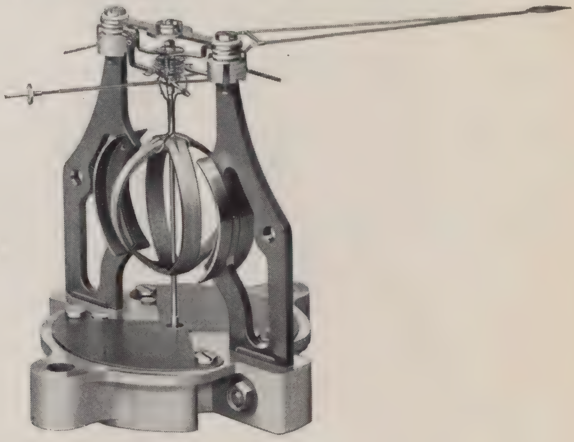


Figure 2

very clearly shown in Figure 1 just above the junction of the pointer and the staff. The filaments are sufficiently strong to be self-supporting.

Since the movable coils do not come under the influence of any mechanical torque, such as is caused by springs, the pointer may rest at any position on the scale when the instrument is not in operation.

The relation of the complete movement to the case, self-contained resistors and scale is shown in Figure 3.

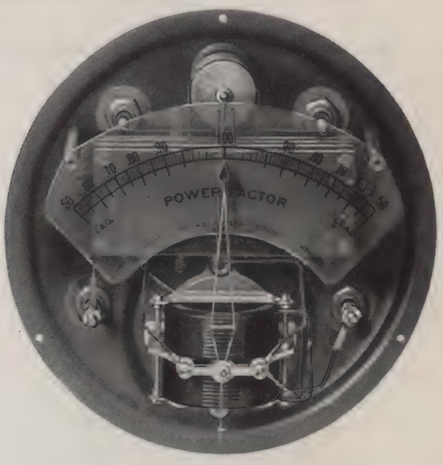


Figure 3

Theory

Weston Power Factor Meters are made as Single Phase, Two Phase and Three Phase instruments. Each form will be dealt with in the following discussion.

Single Phase Instrument

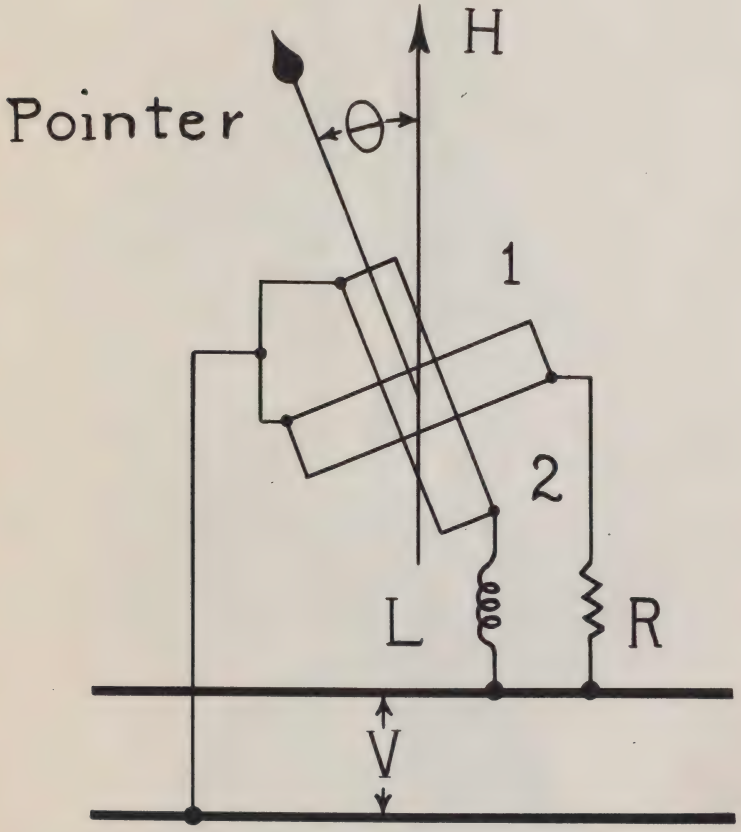


Figure 4

Coils 1 and 2 are the two movable coils which are rigidly mounted at right angles to each other and fastened to the pivoted staff so as to be capable of rotation without spring control. They rotate in the magnetic field H which is produced by the main circuit current as it passes through the field coils. The magnetic field is nearly uniform which condition is achieved by virtue of the elongated shape of the field coil. For this analysis we will assume the field distribution as being uniform. This assump-

tion does not enter into the calibration of an instrument as each scale point is put in by comparison with a standard instrument. The direction of the magnetic field H is shown by the arrow H in the diagram. It is in phase with the main circuit current which produces it.

Coil 1 is connected in series with a resistor R across the line voltage V. Coil 2 is connected in series with an inductance L across the same voltage. The current i_1 in coil 1 is in phase with the line voltage V, whereas the current i_2 in coil 2 is practically in quadrature with the voltage V since the reactance of L is very large in comparison to the resistance of coil 2.

Referring to the diagram, let coil 2 for any position it may assume in use, make the angle θ with the direction of the field H. It follows that the angle between coil 1 and H is $(90°\text{-}\theta)$. The instrument pointer is in the plane of coil 2.

Assume n_1 and n_2 to be the number of turns on coils 1 and 2 respectively.

The directions of the coil windings and the currents in the coils are such that the coils tend to rotate in opposite directions. The torque acting on coil 1 is $Hi_1n_1 \cos\phi \sin\theta$ and that on coil 2 acting in an opposite direction is $Hi_2n_2\cos(90°\text{-}\phi) \cos\theta$ which equals $Hi_2n_2\sin\phi \cos\theta$ where ϕ is the phase angle between the voltage V and the current I passing through the field coils and $\cos\phi$ is the power factor to be measured.

Since there is no spring control these torques balance each other or $Hi_1n_1\cos\phi \sin\theta = Hi_2n_2\sin\phi \cos\theta$ or

$$\frac{\sin\theta}{\cos\theta} = \frac{i_2n_2}{i_1n_1} \times \frac{\sin\phi}{\cos\phi} \qquad \text{that is}$$

$$\tan\theta = \frac{i_2n_2}{i_1n_1} \tan\phi$$

If $i_1n_1 = i_2n_2$ by construction and adjustment then $\tan\theta = \tan\phi$ or $\theta = \phi$. Under these conditions the angular deflection of the pointer is equivalent to the phase angle of the circuit.

It is desired in practice however, to have the instrument scale indicate power factor with the unity power factor mark at the center of the scale and usually the 50 per cent. leading and lagging marks at the extremities of the scale, 43° each side of the unity mark. To accomplish this the values of i_1n_1 and i_2n_2 must be so chosen that $\tan 43° = \frac{i_2n_2}{i_1n_1} \tan 60°$ since the angle whose cosine is 0.50 is 60°, or $\frac{i_2n_2}{i_1n_1} = \frac{\tan 43°}{\tan 60°} = \frac{0.932}{1.732} = 0.538$

As previously stated, this exact ratio cannot be used in an actual scale determination since the magnetic field H is not absolutely but only nearly uniform.

It is desirable at this point to call attention to a very impor-

tant limitation in the use of the SINGLE PHASE INSTRUMENT. This instrument can be adjusted for a definite frequency only and can be used with accuracy only on that frequency.

This follows directly from the fact that current i_2 depends not only upon the voltage V but also upon the reactance of the inductive circuit containing L and since the reactance is 2π fL where f is the frequency, it is obvious that i_2 varies inversely as the frequency, which seriously affects the accuracy of the instrument if the frequency for which the instrument is adjusted is materially departed from.

Furthermore, since a reactor is used to split the phase, the instrument is strictly accurate for sinusoidal currents only, since the reactor for all practical purposes of measurement diminishes to a negligible value all harmonics and allows only the fundamental wave in coil 2 to fully act electrodynamometrically upon the current in the field coils.

Two Phase Instrument

The theory of the two phase power factor meter is the same as that of the single phase instrument. Instead of using the inductance L in series with coil 2, the quadrature current i_2 in coil 2 is obtained directly from one of the two phases of the circuit. In this instrument the pointer is also in the plane of coil 2.

Three Phase Instrument

In this instrument the pointer is placed so that it makes equal angles with the planes of the two coils.

Coil 1 is energized by the voltage across lines A C and coil 2 by that across lines B C of the three phase circuit shown in the diagram. The field coil is connected in series with line C.

At 50 per cent. power factor, which it is desired to indicate at the extremities of the scale 43° each side of the unity mark, one of the two movable coils has no torque owing to the fact that the current in it is in quadrature with the field current I in line C. The pointer therefore must be placed midway between the two coils as stated above.

The torque due to coil 2 is

$Hi_2n_2 \cos(30° - \phi) \cos(45° + \theta)$ and that due to coil 1

$Hi_1n_1 \cos(30° + \phi) \cos(45° - \theta)$ which follows from the trigonometrical relations of the three phase circuit.

Equating these and making $i_1n_1 = i_2n_2$ which is accomplished by construction and adjustment we get $\tan\theta = \frac{\tan\phi}{1.732}$ that is the tangent of the angular deflection of the pointer is proportional to the tangent of the phase angle of the circuit and therefore the scale may be calibrated in terms of power factor.

It is obvious in the case of the two and three phase instru-

ments that they can be used only on circuits which are balanced. Since the field coil is connected in only one line the instrument really measures the true power factor in that line and if the

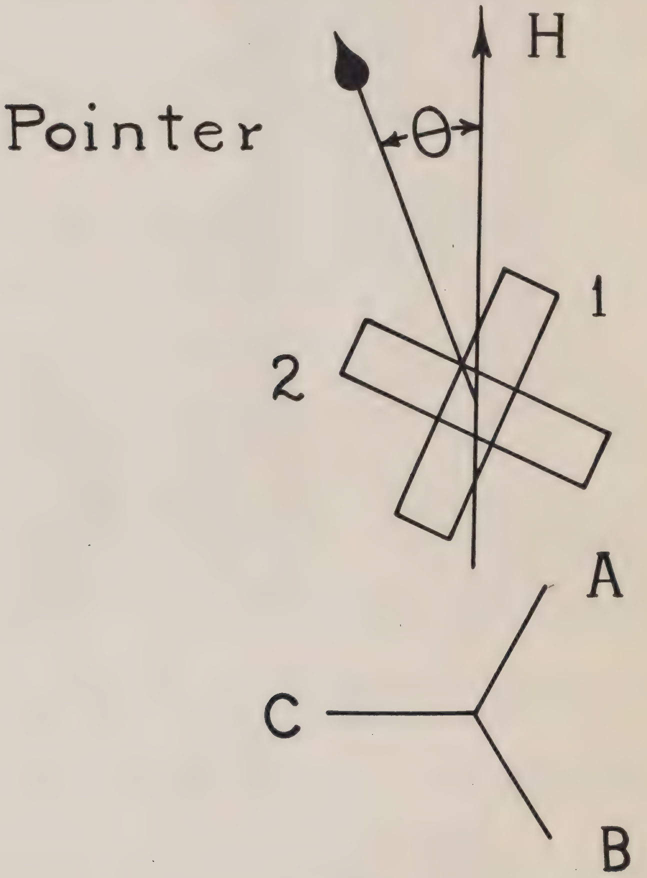


Figure 5

system is unbalanced it gives no indication of the power factor of the other phases.

Calibration

In the calibration of power factor meters at the Weston Plant special apparatus is employed which greatly facilitates the work. It is possible, however, to calibrate and check these instruments using two ordinary dial box resistors and a source of direct current or single phase alternating current in which the current and voltage are in phase.

The method consists in passing a current of proper value for the current range of the instrument and approximately in phase with the supply voltage through the field coils and applying the supply voltage to the movable coils with a dial box in series with each movable coil. All resistors contained within the instrument must be disconnected before this check can be made. The current passing through one of the movable coils should have a value approximately equal to 50 milliamperes. In single phase instruments the current in coil 1 should be adjusted to this value when possible to do so.

To obtain the various pointer positions it is then necessary to vary the ratio of the movable coil currents according to the fundamental law of the instrument.

For single and two phase instruments the ratio of currents is expressed by $\frac{i_1}{i_2} = k \tan\phi$; k is a factor which can be experimentally obtained for the 50 per cent. power factor mark which is the end position of the scale corresponding to a power factor angle of $\phi = 60°$. From the value of $\tan\phi$ and the ratio $\frac{i_1}{i_2}$ as determined, k is calculated. The following example will show how to locate a point on the scale. We will check the 70 per cent. power factor mark. Then 0.7 is the cosine of the power factor angle ϕ which we find from trigonometric tables to be 45° 30′. The tangent of this angle is $1.0176 = \tan\phi$. Assume $k = 0.54$, then $\frac{i_1}{i_2} = 0.54 \times 1.0176 = 0.549$. If $i_1 = 0.05$ ampere $i_2 = 0.091$ ampere which is too high for the coil to carry; therefore we will make i_2 equal to 0.05 ampere by adjustment when i_1 will equal 0.0275 ampere.

For the three phase instrument the expression is

$$\frac{i_1}{i_2} = \frac{1.732 - \tan\phi}{1.732 + \tan\phi}$$

For the 70 per cent. power factor mark we find $\phi = 45°\ 30'$ and $\tan\phi = 1.0176$, therefore $\frac{i_1}{i_2} = \frac{1.732 - 1.0176}{1.732 + 1.0176} = 0.26$, but if i_1 is equal to 0.05 ampere then $i_2 = 0.192$ ampere which is too high for the coil; therefore we will make $i_2 = 0.05$ ampere and i_1 will equal 0.013 ampere.

The Single Phase Reactor

The reactor, which is illustrated in Figure 6, is only used with single phase instruments. Its purpose is to produce the proper phase relation between the two movable coil currents. In the polyphase instruments this relation is obtained by virtue of the

natural characteristics of polyphase circuits. Resistors are used to limit the movable coil currents to their proper values.

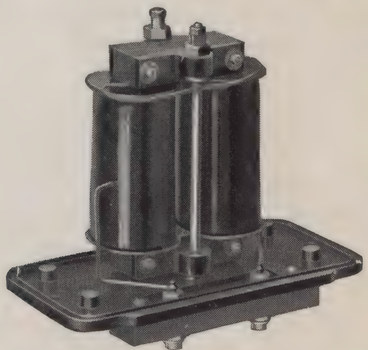


Figure 6

The reactor consists of two coils of copper wire of proper number of turns and suitable dimensions to give the desired inductance value, which are placed over special form of iron core.

The core is made up of very thin laminations of special steel securely fastened together to prevent vibration and change of the reactance value due to relative motion of the laminations. The core is provided with a special form of air gap located within the coils. This is done to eliminate the effect of stray or leakage fields which would be set up about the air gap if it was located outside of the coils.

By proper design and the use of specially selected materials the reactor has been made to retain its original value under varying conditions of service.

Adjustment of the reactor is accomplished by varying the length of the air gap.

Standard Weston Instruments

Weston Power Factor Meters are made in two sizes of switchboard instruments known as models 215 and 356, for use on single phase, two phase three wire and three phase three wire circuits. The two phase three wire instrument used in conjunction with two potential transformers can be applied to two phase four wire circuits.

All two phase and three phase instruments are provided with an external resistor box irrespective of the range of the instrument. This is contrary to the information contained in our catalogs but it is the practice which will be followed from now on.

Single phase instruments are provided with an external resistor box in addition to the reactor box on ranges above 150 volts.

Weston Frequency Meters

An alternating current is a current which alternates regularly in direction, commonly considered as having successive half waves of the same shape and area. One complete set of positive and negative values of an alternating current is called a cycle. Frequency is the number of cycles passed through in one second of time. A Frequency Meter is an instrument which indicates the number of cycles per second or the frequency.

The speed of synchronous motors, induction motors, synchronous converters, motor generators and other alternating-current apparatus depends on the frequency of the supply circuit. Change in frequency is accompanied by a change in speed. The frequency must be accurately known when large systems are to be tied together. Changes in frequency also cause corresponding changes in the reactance of circuits, which may be a considerable disadvantage. A consideration of these facts leads one to appreciate the need for a reliable frequency meter.

Weston Frequency Meters may be considered as divided into two groups, those in one group including instruments for use on ordinary commercial frequencies between 25 and 133 cycles per second, and those in the other group, instruments for use in radio service at frequencies of the order of 500 and 1,000 cycles per second. Model 214 and Model 355 Frequency Meters are in the first group. The second group is comprised of Model 355 only and then in a type known as a resonant type of instrument. These two groups will be considered.

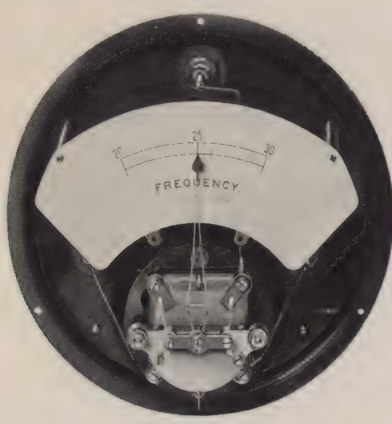


Figure 1

Reference to Figure 1 showing a Model 214 Frequency Meter with the cover removed, enables one to obtain a clear idea of the

internal arrangement of the instrument, which is for use on ordinary commercial frequencies.

The instrument has two field coils placed perpendicular to one another. Each coil is composed of two sections. The coils are flat in form and are proportioned to produce a strong field of uniform intensity. One pair is slipped inside the other.

The movable system consists of a very thin iron needle of particular form having proper magnetic characteristics, fastened to a pivoted staff to which the pointer and air damper vane are also attached. The iron piece rotates freely within the field coils. There are no springs or other connections to the movable coil.

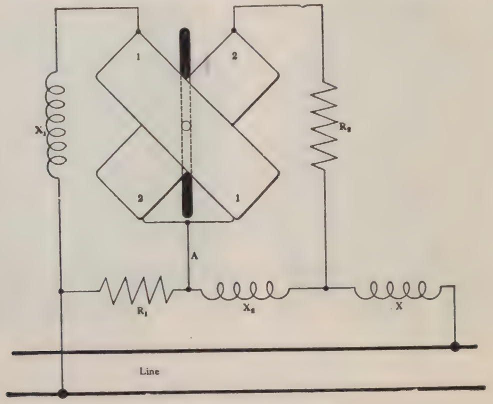


Figure 2

The electrical circuits of this instrument are shown in Figure 2, which is a view from the rear of the instrument. The field coils are represented by 1 and 2. The very heavy black line between the coils represents the iron needle in its normal position when the pointer is at the middle of the scale. The needle and pointer are displaced approximately 40° with respect to one another.

The Resistors R_1 and R_2 as well as the Reactors X, X_1, and X_2 are contained in a box which is external to the instrument. The box, with its sides and bottom removed, is shown in Figure 3. The construction of the reactors is described under the "Weston Power Factor Meter." The external appearance of the box is shown in Figure 4.

An examination of Figure 2 discloses that coil 1 is connected in series with the reactor X_1, the combination being shunted by the resistor R_1. Likewise coil 2 is connected in series with the resistor R_2, the combination being shunted by the Reactor X_2. Coils 1 and 2 are connected in series as shown at A. The circuit formed is similar to a Wheatstone Bridge circuit. The local circuit consist-

ing of the field coils, resistors and reactors are connected to the main circuit through the reactor X which serves to choke out the harmonics of the alternating voltage applied to the instrument.

The operation of the instrument is as follows. When the normal frequency (pointer at the center of the scale) is applied to the instrument the currents in coils 1 and 2 are such that the fields produced are of equal strength. Each coil therefore acts on the needle to the same extent with the result that the needle occupies a position midway between them.

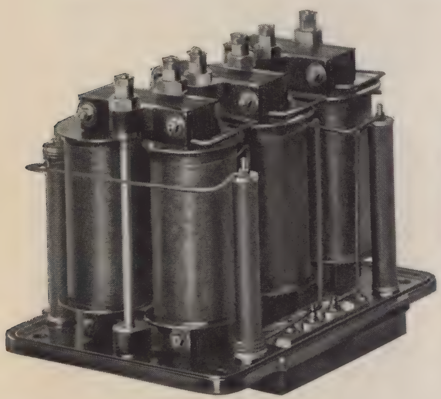


Figure 4

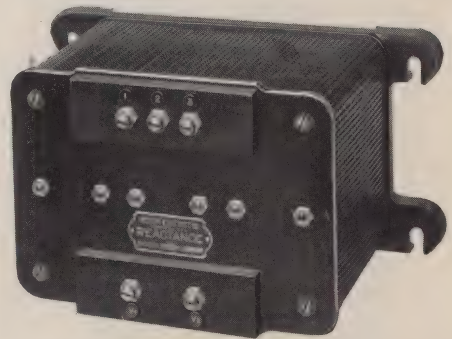


Figure 3

Suppose the frequency is increased. The reactance of the reactors X_1 and X_2 is increased and less current flows in coil 1 and more in coil 2. The change in the currents in the coils causes the fields to change in a corresponding manner, which causes a shifting of the resultant magnetic field toward the coil carrying the smaller current; which in this case is coil 1. The iron needle always being in the direction of the resultant magnetic field, will follow to the new position of the resultant field. As it does so the pointer will move up the scale and indicate the new value of frequency.

With a decrease in the frequency from the normal value, the current in coil 1 will increase and that in coil 2 will decrease because the reactance of X_1 and X_2 will become less as the frequency is reduced. The direction of the resultant magnetic field is then shifted toward coil 2 with a corresponding movement of the needle and the pointer.

For each value of frequency within the limits of the total frequency range of the instrument, the needle and pointer will assume a definite position which is indicated on the scale in terms of cycles per second.

Model 214 and Model 355 Frequency Meters are made for direct connection to the circuit in normal voltage ranges of 110 and 220 volts. The 110 volt instrument should not be used on voltage lower than 100 volts, nor should the 220 volt instrument be used on voltages lower than 200 volts as voltages lower than those stated do not give sufficient torque to operate the instruments satisfactorily. The maximum voltages which may be applied to the 110 volt instrument is 150 volts and to the 220 volt instrument is 300 volts. These voltages should not be exceeded because the instruments will be unduly heated and possibly burned out. For best operation the high limit of voltage should not be above 130 and 260 volts respectively.

For use on circuits, the voltage of which is above 220 volts normal, it is necessary to employ a 110 volt instrument and a potential transformer.

Theoretically these instruments are correct only on true sinusoidal wave form, but through the use of the reactor X shown in Figure 2 harmonic effect is very successfully eliminated so that the instruments give perfectly satisfactory service on any wave form found in commercial circuits.

Temperature change has no effect on the indications of the instrument.

The 110-volt instruments operating at 25 or 60 cycles require for their operation about 4.2 watts and 9.5 voltamperes. The 220-volt instruments require about 5 watts and 19 voltamperes.

The resonant type of frequency meter for use on frequencies in the vicinity of 500 and 1,000 cycles per second is only made in Model 355. It is known as Type 2. The arrangement of the field coils is the same as for the instruments previously described.

The Type 2 instrument is self-contained; the reactors, similar in design to those illustrated in Figure 3 but considerably smaller in size together with the resistors and the condenser, are contained within the instrument case.

Figure 5 illustrates diagramatically the electrical circuits of the instrument. The vertical field coils designated as 1 are connected to the line through a resistor R, a condenser C, and two protecting reactors X_1 and X_2. The horizontal field coils 2, having a reactor X in series with them; the coils and the reactor are shunted by the condenser C.

By referring to Figure 5 it will be seen that the current which passes through the reactor X traverses field coil 2. This is a lagging current. It produces in coil 2 a magnetic field tending to

hold the needle in a plane perpendicular to the coils. This lagging current also traverses coil 1.

The current which passes through the condenser C likewise traverses coil 1 but is a leading current. The resultant of the lagging and leading currents in coil 1 produces a magnetic field tending to displace the needle from the normal position.

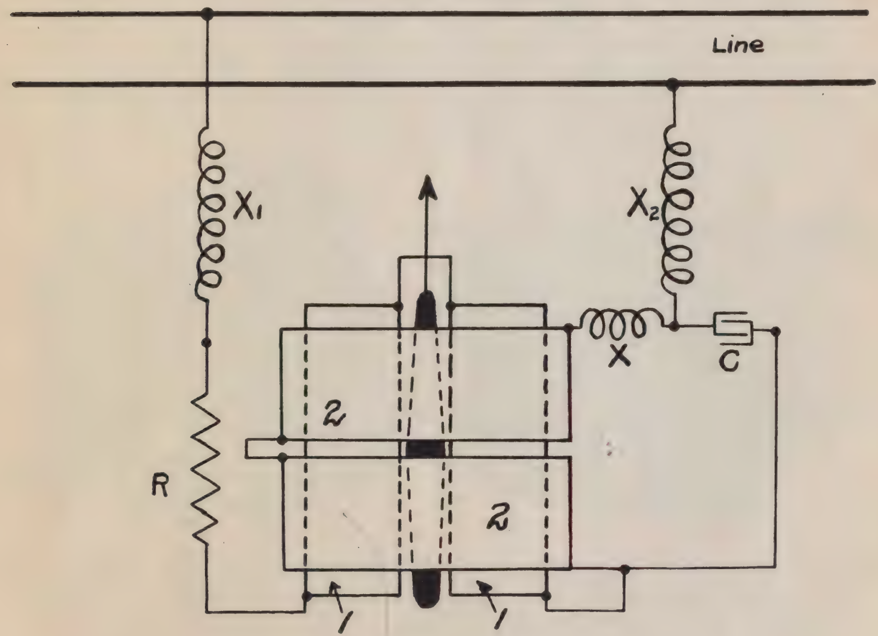


Figure 5

When the frequency is lower than normal the lagging component of the current in coil 1 preponderates because of the decrease in reactance of reactor X and the increase in reactance of condenser C. Therefore the effect of the resultant currents in coil 1 is to deflect the needle to the left of its normal position.

When the frequency is higher than normal the leading component of the current in coil 1 preponderates as the reactance of X is increased and that of C decreased. The resultant current now causes the needle to deflect to the right of its normal position.

At normal frequency the effect of the fundamental of the current passing through coil 2 is very greatly magnified by the circuit 2, X, C becoming resonant.

Because of this the torque exerted on the needle to keep it at its normal position is large, whereas the current taken from the line for the operation of the instrument is very small.

Because the resonant circuit amplifies the effect of the fundamental only and the reactors X_1 and X_2 together with the resistor R prevent the passage of harmonics through the field coil 1, this instrument is practically not affected by distorted wave form, indicating with the same degree of accuracy on a sinusoidal wave form or on a wave having practically a rectangular form.

Model 355 Type 2 is most generally made for use on 500 cycle and 1,000 cycle circuits. These instruments are designed for a normal voltage range from 110 to 220 volts with an overload capacity which allows the voltage to reach 350 volts without injuring the instrument. This renders the instrument suitable for use on radio telegraph sets where the open circuit voltage is high but the operating voltage considerably lower.

When the 500 cycle instrument is operated on minimum voltage (110) about 1.5 voltamperes are taken from the line. At the maximum voltage (350) this becomes about 15 voltamperes.

Besides the Weston Frequency Meters there are a few other forms in use which will be briefly mentioned. A common form is that which employs vibrating reeds. Tuned reeds are caused to vibrate by being brought under the influence of an electromagnet energized from the circuit whose frequency is to be determined. The reed having a natural period corresponding to the frequency of the circuit is set in vibration. The frequency is read on a scale figured in cycles per second.

Another form of frequency meter employs two movable coils rigid with respect to one another and approximately at right angles. These rotate in a field coil. No springs are used. The system resembles that of the Weston Power Factor Meter. The total instrument current passes through the field coil. Each movable coil is connected in series with a condenser and a reactor. One of the circuits thus formed is adjusted to be resonant near the low limit of frequency and the other near the high limit of frequency. The currents in the coils depend on the applied frequency. At normal frequency they are the same and the coils are symmetrically placed with respect to the field coil. For any other frequency one coil carries a larger current than the other. The reaction between the coil carrying the larger current and the field coil causes the movable system to rotate. The coil carrying the larger current is placed in a less advantageous position and the one with the smaller current in a more advantageous position. As the two movable coils oppose one another a balance will be obtained when the reactions between each coil and the field coil become of equal intensity.

An induction form of instrument is made by one American manufacturer which employs two so-called motor elements acting on a flat aluminum plate of special shape. The motor elements

tend to turn the plate in opposite directions. One element is connected in series with an inductance and the other in series with a resistance. At normal frequency the motor effects are equal. When the frequency is changed one element exerts a greater effect than the other causing the plate to turn, but because of the shape of the plate the effort is gradually diminishing until an equality is again obtained.

All of these frequency meters meet practical requirements in a more or less satisfactory way. Entirely satisfactory service is to be had only through the use of the Weston Frequency Meters because of their simplicity, superior design and higher grade of workmanship.